STATUS REPORT:

SITE-WIDE GROUNDWATER FLOW MODELING

AT THE ROCKY FLATS PLANT

GOLDEN, COLORADO

EG&G ROCKY FLATS, INC.

Environmental Management

Geosciences Division

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1.0 INTRODUCTION

This report presents a discussion on the status of a task to model the groundwater flow regime at the Rock Flats Plant (RFP) in Golden, Colorado The results presented here represent the first effort to model the groundwater system contained within the unconsolidated surficial materials at the RFP

The RFP is located in northern Jefferson County, Colorado, approximately 5 miles south of Boulder and 16 miles northwest of downtown Denver The plant site consists of 6,550 acres of federally owned land of which 6,170 acres is a buffer zone surrounding an inner industrial complex The RFP is a federal facility which began operation in 1951 to support nuclear weapons production and is owned by the Department of Energy, but operated by a private contractor

A history of industrial activities related to the plant's mission have resulted in the contamination of the groundwater beneath the RFP Groundwater flow modeling has been undertaken at the RFP in order to understand the consequences of this contamination The flow modeling presented here is intended to provide an overview of the near-surface flow system beneath the Rocky Flats Plant

The goals of this modeling project are

1 To aid in the hydrogeologic characterization of the RFP
2 Provide basic information for estimating groundwater travel times
3 Assist in understanding groundwater/surface-water interactions
4 Provide groundwater mass-balance information
5 Understand how the individual Operable Unit (OU) flow systems interact

The proposed methods by which a groundwater flow model of the RFP can address these goals are, respectively

1 By providing a comprehensive picture of the groundwater flow regime at the RFP, the model will link the observational data from observation wells into a single interpretation that will consider such factors as hydraulic conductivity, bedrock topography, and groundwater recharge rates

2 Groundwater travel times can be computed by using the mass flux rates determined by the model

3 As envisioned, a fully implemented flow model will include mass transfer to and from surface water bodies, allowing groundwater/surface-water interactions to be investigated

4 In addition to providing estimates of recharge to the groundwater system, the mass flux rates computed by the model can be used to determine the volumes of water flowing through different areas at the RFP

5 Because the site-wide flow model will incorporate all the Operable Units (excluding OU 3) and the intervening areas between the OUs, it will provide the means to analyze the site-wide flow system in the context of the individual OUs

Each chapter of this report discusses a different topic related to the site-wide groundwater flow modeling project Chapter Two presents a general discussion of the geology and hydrology of the RFP This discussion provides the general hydrogeologic conceptual model on which the implementation of the flow model is based A brief discussion of the computer code used for the site-wide flow modeling is given in Chapter Three Chapter Four discusses

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the actual implementation of the flow modeling computer code for use at the RFP The status of the calibration for the flow modeling and a discussion of additional refinements for improving the model are given in Chapters Five and Six, respectively

2.0 CONCEPTUAL HYDROGEOLOGIC MODEL

2.1 GEOLOGY

The RFP is located four miles east of the Front Range section of the Southern Rocky Mountain province, along the western margin of the Colorado Piedmont section of the Great Plains physiographic province (Spencer, 1961) The RFP is on a pediment that dips approximately one degree to the east, and is dissected by several easterly flowing, ephemeral streams, that either originate on plant site, or one to two miles to the west

The geology of the area around the RFP consists of several surficial deposits overlying sedimentary bedrock layers The surficial deposits are made up of pediment alluvium, colluvium, valley-fill alluvium, and artificial fill that unconformably overlie the bedrock formations These near-surface alluvial deposits range from Quaternary to Pleistocene in age The bedrock consists of several sedimentary formations with a regional dip of approximately two degrees to the east, ranging from Pennsylvanian/Permian to Cretaceous in age The subcropping strata become progressively older from east to west West of the RFP, the sedimentary strata are exposed along the western limb of a monoclinal fold The dip increases to the west as the layers abut against Precambrian-aged crystalline rocks (EG&G, 1991) The total thickness of the geologic section for the Paleozoic and the Mesozoic-aged strata is approximately 13,000 feet

The uppermost hydrostratigraphic unit at the RFP exists as an unconfined water-bearing unit This upper water-bearing unit is primarily contained within the unconsolidated alluvial materials and includes the Rocky Flats Alluvium, colluvium, and the valley-fill alluvium In addition, shallow, subcropping bedrock sandstones and the upper weathered bedrock are included in the conceptual definition of the uppermost hydrostratigraphic unit at the RFP

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The Rocky Flats Alluvium is a gravelly pediment, alluvial-fan deposit consisting of poorly sorted, angular to rounded, coarse-grained gravels, sands, and clays with thicknesses of as much as 100 feet The colluvium predominantly consist of a thin deposit of silty clay and clayey silt, with some gravel and sand, and is produced by mass wasting along valley slopes The valley-fill deposits are represented by well to poorly sorted, reworked materials of Rocky Flats Alluvium, colluvium, and weathered bedrock These deposits are found in the base of drainages throughout the area Both the colluvium and the valley-fill alluvium range in thickness from less than one foot to several tens of feet

2.1.1 Rocky Flats Alluvium

The Rocky Flats Alluvium is a Quaternary-aged pediment gravel deposited as a laterally coalescing alluvial-fan deposit derived from Coal Creek Canyon The deposit thins from west to east, with thicknesses ranging from one to approximately 100 feet In the central portion of the RFP, the deposit is approximately 15 to 25-feet thick It was deposited across a gently sloping erosional surface cut into the underlying bedrock The slope of the pediment near its apex is approximately 1 5 degrees to the east (EG&G, 1992b)

The Rocky Flats Alluvium consists of poorly to moderately sorted, poorly stratified clays, silts, sands, gravels, and cobbles In some areas the Alluvium has developed a significant near-surface caliche layer The Rocky Flats Alluvium varies in color and ranges from light to dusky brown, dark yellowish orange, grayish orange, to dark gray (EG&G, 1991) Subsequent dissection and headward erosion by creeks in the area have cut through the alluvium into the underlying bedrock, exposing the base of the alluvium along some valley walls

2.1.2 Colluvium

Colluvial deposits consist of surface soil, displaced Rocky Flats Alluvium, and slump deposits resulting from mass-wasting along valley slopes These deposits vary in thickness from less

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than one foot to approximately 30 feet The colluvium is predominantly silty clay and clayey silt with some gravel and sand

2.1.3 Valley-Fill Alluvium

The valley-fill alluvial deposits, present in the bottoms of modern stream drainages, are composed of linear deposits of cobbles, gravels, and sands These deposits are typically less than 10-feet thick Usually these deposits contain more sand than the Rocky Flats Alluvium and are better sorted

2 2 CLIMATE

The area of Colorado in which the RFP is located, exhibits a semi-arid climate and receives an average of approximately 15 inches of precipitation annually (EG&G, 1992a) On the average, daily summer maximum temperatures at the plant site range from 55 to 85 degrees Fahrenheit (°F) and winter maximum temperatures range from 20 to 45° F Approximately 50 percent of the precipitation is received from snowfall during the winter and spring Summer thunderstorms account for approximately 30 percent of the precipitation, with the remainder being received as light rain and snow during the fall Approximately 85 inches of snow are deposited annually Computed potential evapotranspiration is estimated to be approximately 39 inches per year (Fedors and Warner, 1993)

2.3 GROUNDWATER HYDROLOGY

2.3.1 General

The primary source of groundwater within the unconsolidated surficial materials at the RFP is the infiltration of precipitation, either from direct rainfall or snowmelt Other sources include recharge from streams, ditches, and ponds, as well as some subsurface flow from upgradient recharge areas Groundwater flows predominately in a west-to-east direction, following the general bedrock and topographic gradients The highest groundwater elevations (and greatest saturated thicknesses) typically occur in the spring, with the lowest elevations occurring in the

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fall and winter Losses from the surficial groundwater system include discharge to surface water through streams and seeps, evapotranspiration, and recharge to underlying bedrock Subsurface groundwater discharge to off-site areas is believed to take place primarily along the major drainages

The uppermost, unconfined aquifer at the RFP consists primarily of unconsolidated alluvial material These alluvial materials include the Rocky Flats Alluvium, which forms a high, gently sloping plateau across the plantsite, colluvium located along valley slopes, and valley fill alluvium present in the modern stream drainages In the western part of the RFP, where the thickness of the Rocky Flats Alluvium reaches 90-feet, the depth to the water table is 50 to 70-feet below the surface In general, the depth to the water table becomes shallower from west to east as the alluvial material thins Seeps are common along valley slopes at the base of the Rocky Flats Alluvium where it is in contact with claystones of the Arapahoe/Laramie Formations During dry portions of the year, extensive areas of the alluvial materials may become unsaturated The location and extent of these areas is time-transgressive

2.3.2 Groundwater Flow

A contour map of water level elevation was constructed using data from wells within the unconsolidated surficial materials, collected during the time period from April 1, 1992 to May 30, 1992 (see Figure 2-1 and Plate 1) This time interval is used here to represent conditions during spring 1992 Variations in the screened interval and depth of penetration of the wells may introduce some variation between the observed and actual groundwater elevations

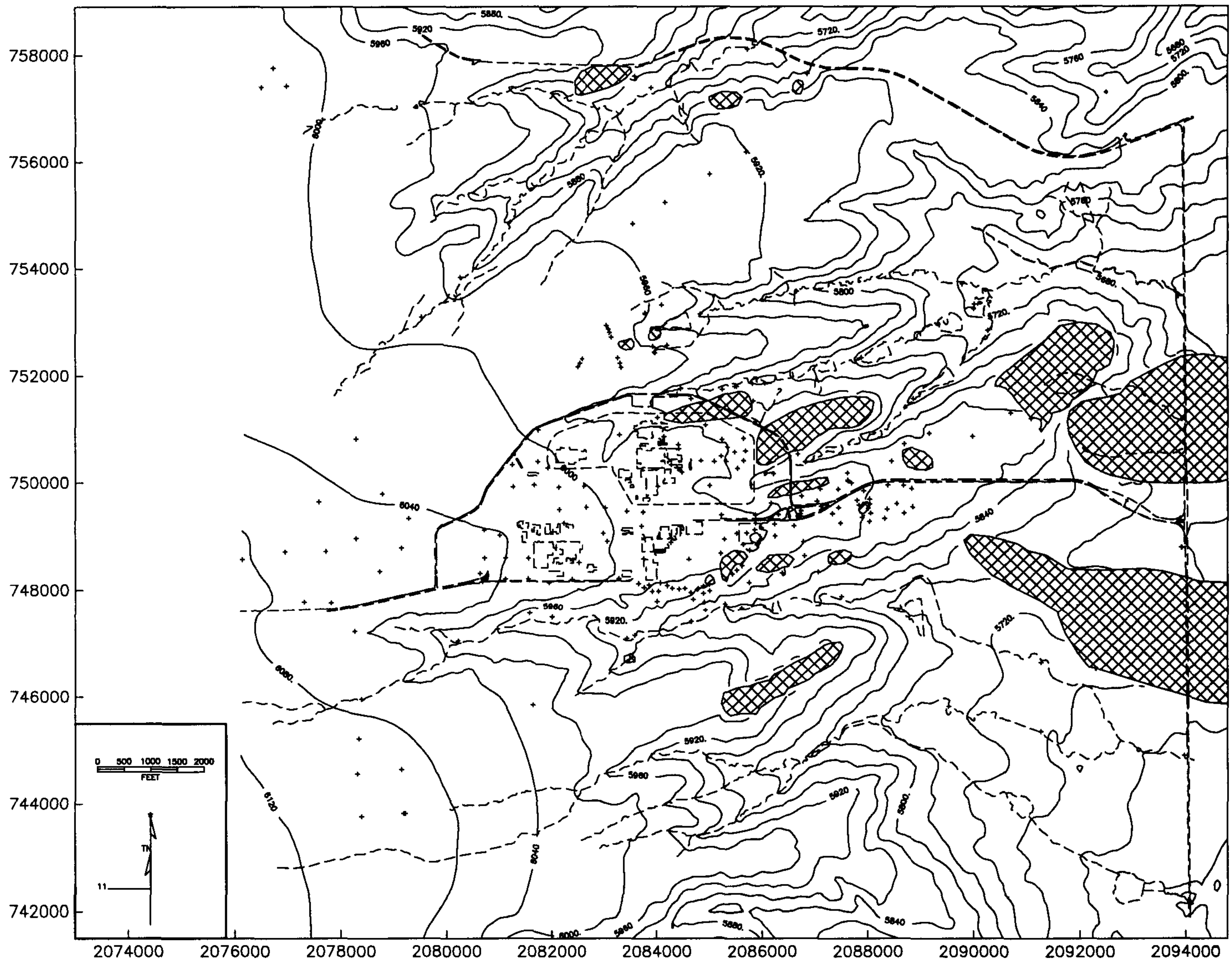

Figure 2-1 Contours of water table elevation for the unconsolidated surficial materials at the RFP Contour interval is 40 feet Elevations are in feet above mean sea level Unsaturated areas are shown by hatchured pattern Data points used to create map are shown by small + symbols RFP structures, roads, and streams are shown using dashed lines

Generally, groundwater in the Rocky Flats Alluvium flows laterally along the top of the claystone bedrock surface It moves in an easterly direction in areas upgradient of the RFP, and in a semi-radial pattern to the north, east, and south Typically, the underlying claystones have a low hydraulic conductivity, on the order of 1 x 10^{7} centimeters per second (cm/s) (EG&G, 1992c, Table 1) This low hydraulic conductivity limits the amount of vertical flux from the surficial materials into the bedrock This effectively constrains the flow in the overlying surficial materials to a primarily lateral course In some areas with a high density of borehole locations, there is significant evidence that bedrock topography controls groundwater flow within the alluvial materials This process is particularly important in areas with a thin saturated thickness

Groundwater flow in colluvium is characterized by relatively steep horizontal gradients toward stream drainages, and a highly variable saturated thickness controlled by bedrock topography and proximity to recharge sources (i e , subsurface discharge from the Rocky Flats Alluvium) Flow through the colluvium provides subsurface recharge to the valley-fill alluvium Groundwater within the valley-fill alluvium flows parallel to the main stream drainage The groundwater and surface-water systems within the valley-fill alluvium are closely related, and may exchange mass in either direction at various locations along the drainage (Fedors and Warner, 1993)

Water-level differences between bedrock and alluvial wells indicate a strong downward vertical hydraulic gradient Although a strong gradient exists, the amount of vertical flow through the bedrock claystones is assumed to be small based on the fine-grained lithology and the limited occurrence of fractures at depth observed in cores Fracturing, where evident, is most abundant in the weathered bedrock zone Cores from borings indicate that fractures occur individually and in discrete zones, and that they are generally oblique to near vertical In addition, some fractures exhibit mineralized areas (i e , iron staining) in the upper portion of the bedrock, but appear to heal with increased depth (EG&G, 1992d)

2 3.3 Anthropogenic Effects

The introduction of manmade surface and subsurface water-flow control features has resulted in a noticeable impact to the RFP groundwater flow regime These features typically result in increased or decreased groundwater elevations near the structure The structures affecting the largest areas within the RFP groundwater flow system are, the groundwater interception and diversion system at the existing RFP landfill, the solar evaporation ponds groundwater intercepter trench system, the OU-1 French Drain system, and the footer drains associated with the subsurface portions of many of the buildings within the industrial complex

The groundwater interception and diversion system at the existing RFP landfill has the affect of lowering the groundwater table within the landfill Figure 2-2 shows hydrographs from two closely spaced (~100 feet apart) wells inside and outside of the interception and diversion system As shown by this figure, well 6587, which is inside the groundwater interception system, has a consistently lower groundwater elevation compared to that of well 6487, which is directly adjacent, but outside of the interception system

The groundwater intercepter trench system for the solar evaporation ponds collects groundwater from the unconsolidated surficial materials on the slope between the solar evaporation ponds and Walnut Creek The effect of this is a desaturated area on the slope north-east of the solar ponds (see Figure 2-1 or Plate 1)

The OU-1 French Drain system is designed to intercept all subsurface water in the unconsolidated surficial materials which flow down the hillslope towards Woman Creek This system was completed in April 1992, as such, it is too early to fully define its effect on the groundwater flow system Although they are of a smaller scale than the drainage systems discussed above, building footer drains may have a notable impact on groundwater elevations due to the high concentration of buildings in the industrial area at the RFP

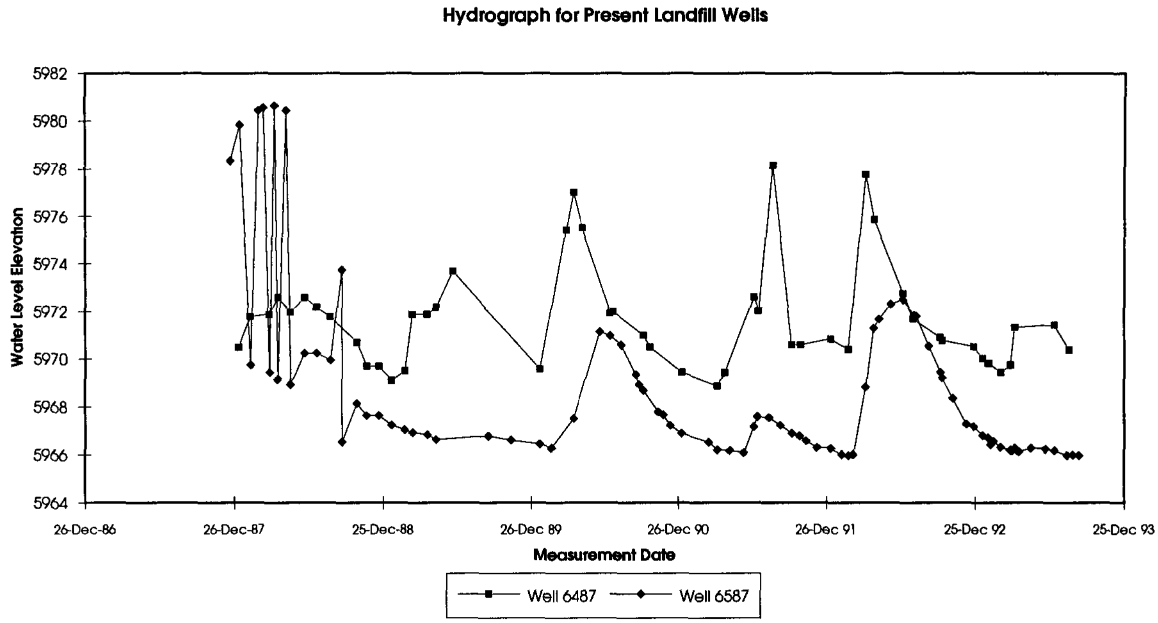

Figure 2-2 Hydrograph for observation wells in the present landfill showing the influence of the groundwater interception and diversion system

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In addition to the relatively constant influence of the anthropogenic effects discussed above, other effects with a more transient nature influence the groundwater system at the RFP Most notable of these are the spray irrigation of excess surface water, and the apparent effect of groundwater sampling events on subsequent water level measurements in wells with low recovery rates

Although some limited spray irrigation is still done at the RFP, it was much more prevalent in the past Spray irrigation is the spraying of water into the air in an attempt to enhance evaporation of the water This was typically done over non-developed areas so those waters that did not evaporate infiltrated into the ground or were transported as surface runoff The recharge induced by these practices can be seen in hydrographs from wells in the affected areas (Figure 2-3) Hurr (1976, pg 26) also notes the effects of surface irrigation on hydrographs from adjacent wells

The relatively large-scale irrigation practices of the past are not currently in use Spray irrigation of water from the pond east of the present landfill is the only evaporation system known to be in recent operation This system should have minimal impact on the RFP groundwater flow system at the site-wide scale, because it involves a relatively small area and is located directly adjacent to a surface-water body

Although not a large-scale impact on the groundwater flow system, sampling events may cause apparent effects by temporarily lowering the water level in wells that have a long recovery time The hydrograph for well 7087 shows this effect (Figure 2-4) Some of the low water-level measurements are the result of measuring water-level while the well is recovering from a sampling event Several of the water sampling events are followed by a series of lowered water-level measurements that define a exponential curve, similar to a well recovery curve This indicates that the well was still in the process of recovering from the

Hydrograph for well 4186

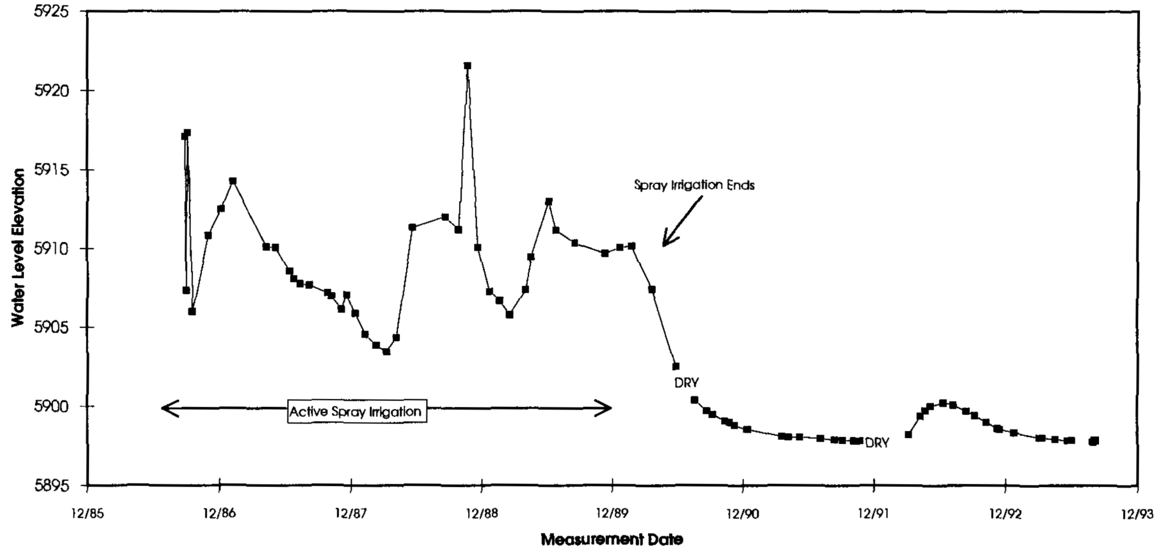

Figure 2-3 Hydrograph showing the affect of spray irrigation on water levels at the RFP A notable decline in water level is observed after spray irrigation practices are stopped

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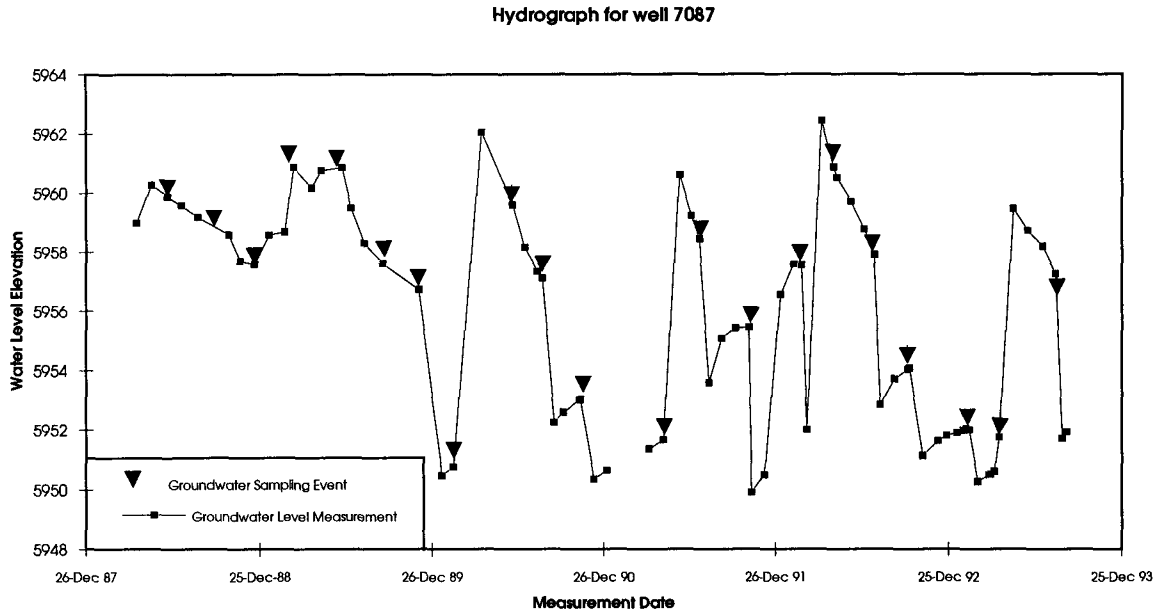

Figure 2-4 Hydrograph showing the influence of sampling events on an observation well with a long equilibration period Filled triangles indicate sampling events The solid line connects water level measurements Note that low water level measurements are commonly associated with a previous sampling event Some portions of water level line exhibit a shape similar to a water level recovery curve

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sampling event when subsequent water-level measurements were made This process may explain some of the erratic water-level fluctuations shown by some wells

2.4 SURFACE-WATER HYDROLOGY

The surface-water system at the RFP is interconnected with the groundwater system Surface-water recharge to the Rocky Flats Alluvium, valley fill alluvium, and colluvium occurs as seepage from streams, ditches, and ponds Conversely, groundwater is discharged as surface water along streams and at localized seeps where groundwater reaches the land surface These seeps typically occur along valley slopes near the base of the Rocky Flats Alluvium

Four streams flow through the RFP North Walnut Creek, South Walnut Creek, Woman Creek, and Rock Creek All of these streams drain the RFP site and are considered to be ephemeral North Walnut Creek and South Walnut Creek converge to become Walnut Creek, which flows toward Great Western Reservoir A diversion canal, operated by the city of Broomfield, diverts flow from Walnut Creek around the reservoir Woman Creek originates west of the RFP and drains the south part of the site Its natural drainage is to the east, towards Standley Lake However, a diversion structure (Mower Ditch), located within the RFP boundaries diverts much of the flow from Woman Creek into Mower Reservoir The Rock Creek drainage is located in the north part of the site It flows to the northeast, eventually joining Coal Creek beyond the northern boundary of the RFP In addition to the natural drainages, nine ditches convey water through the RFP area Except where conveyed by aqueducts, all of these ditches are unlined and tend to lose water through seepage into the underlying subsurface materials

Within the natural drainages a series of detention ponds has been constructed to control the release of plant discharges and to collect surface runoff Ponds located along North Walnut Creek are designated A-1 through A-5, and ponds located along South Walnut Creek are designated B-1 through B-5 Ponds A-1, A-2, B-1, and B-2 are reserved for spill control and are isolated from drainage waters flowing down Walnut Creek Pond B-3 receives treated effluent from the Sanitary Waste Treatment Plant The remaining A and B series ponds receive runoff from the plant's storm-sewer system Pond C-1 is a flow-through reservoir located along Woman Creek Pond C-2 is isolated from Woman Creek and is used to collect diverted surface flow from the South Interceptor Canal along the north slope of the Woman Creek drainage Other surface water features at the RFP include a detention pond located at the existing landfill, and ponds D-1 and D-2 that are part of a diversion canal located near the southeast corner of the RFP

3.0 MATHEMATICAL MODEL

This section discusses general aspects of the computer code used to do the site-wide flow modeling, why this code was selected, and the output generated by the code

The computer code selected for the site-wide flow modeling project was the modular, three-dimensional finite-difference groundwater flow model of the U S Geological Survey (USGS) commonly referred to as MODFLOW (McDonald and Harbaugh, 1988) Below is a discussion of the criteria used in selecting MODFLOW for this project

The main criteria used for selecting the computer code to use for this project were

1. The selected model should be able to incorporate key hydrogeologic processes and accurately represent conditions known to occur at the site

2. The selected model should be able to satisfy the objectives of the study

3. The selected model should be verified using published equations and solutions

4. The selected model should be complete and well documented and preferably available in the public domain

5. The selected model should be practical and cost-effective in terms of actual applications as well as resolution of uncertainty

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The MODFLOW model was selected based on each of the above criteria based on the following observations

1 MODFLOW is a modular program with a wide variety of packages available for simulating different hydrogeologic processes The key hydrogeologic processes at the RFP (areal recharge, groundwater/surface-water interactions, two-dimensional flow in saturated porous media) are all simulated within various MODFLOW model packages

2 The main objective of this project was to provide a saturated flow model that encompasses the main plant and buffer zone areas of the RFP An additional objective, to be addressed in future work, is the implementation of a contaminant transport model based on the saturated flow model MODFLOW meets the main objective by providing a two-dimensional simulation of groundwater flow for a grid work of points covering the area of interest The use of MODFLOW will also allow meeting the future objective because there are models that can use the flow field output from MODFLOW to do particle tracking (Pollock, 1989) and/or fate and transport simulations (Zheng, 1992)

3 MODFLOW is a widely used finite-difference flow model that has gained broad acceptance and recognition (Anderson and Woessner, 1992, van der Heijde et al , 1988)

4 MODFLOW is a complete package for modeling two-dimensional flow through layered porous media, no additional code is required

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for the flow computations The MODFLOW model is documented in a comprehensive USGS publication (McDonald and Harbaugh, 1988), and the source code is available in the public domain

5 Several modeling pre-processors and post-processors are available for aiding in MODFLOW input data development and output analysis The MODFLOW model is widely available and is written in standard FORTRAN 77 It can easily be implemented on any computer that has a FORTRAN 77 compiler These factors provide for the practical and cost-effective application of MODFLOW to the site-wide modeling project The structure and character of the MODFLOW input and output data sets provide sufficient means for standard sensitivity analysis

MODFLOW is a modular, three-dimensional, finite-difference saturated-flow model written in FORTRAN Although capable of simulating vertical flow, MODFLOW is commonly used to simulate two-dimensional layered systems with varying vertical conductance between the layers Vertical and horizontal model dimensions are defined by the thickness of the layers and the row and column spacing, respectively The model grid is implemented in a block-centered fashion

The site-wide flow simulations use the standard, required MODFLOW modules for basic model input (subroutine BAS1) and conductance term calculation (subroutine BCF1) (McDonald and Harbaugh, 1988) A preconditioned conjugate-gradient solver (subroutine PCG2) (Hill, 1990) was used to solve the matrix of equations generated by the finite-difference approximations The optional output control module was also used to provide better control of the format and frequency of the output generated by the model

In addition to the modules discussed above, the recharge package (subroutine RCH1AL) (McDonald and Harbaugh, 1988) and streamflow-routing package (subroutine STR1RP) (Prudic, 1989) were used in the site-wide flow modeling The recharge package was included because areal recharge through precipitation is an important factor in groundwater flow at the RFP Inclusion of the streamflow-routing package was done to incorporate groundwater/surface-water interactions into the model

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4.0 MODEL IMPLEMENTATION

4.1 INTRODUCTION

This chapter discusses the implementation of the groundwater flow simulation code selected for use in the RFP site-wide flow model The implementation of the simulation code involves developing input data for the code that reflect the hydrogeologic conditions at the RFP This chapter also discusses the manner in which the MODFLOW model was transferred to and executed on the computer systems within the Environmental Sciences and Engineering Division of the Environmental Restoration Management Department at EG&G Rocky Flats, Inc

4 2 INSTALLATION AND PREPARATION OF MODFLOW MODEL

The primary source code for the MODFLOW model was obtained from the International Ground Water Modeling Center (IGWMC) located at the Colorado School of Mines in Golden, Colorado The IGWMC is an internationally recognized organization, which acts as a distributor of groundwater-related models and model information The source code for the streamflow-routing package (subroutine STR1RP) (Prudic, 1989) was obtained from the USGS

The FORTRAN source code files were transferred to an IBM RS6000 UNIX workstation for compilation The IBM FORTRAN compiler for these workstations does not recognize I/O unit numbers greater than 99 The I/O unit numbers in the MODFLOW source code were changed to meet this requirement This was the only change made to the original source code and has no impact on the computational aspects of the model

After the MODFLOW source code was installed and compiled, several example problems were executed The output from these sample problems was verified against the documentation provided with the sample problems The output from all the sample problems

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(Appendix A) tested matched the documented output within the expected tolerances (see McDonald and Harbaugh, 1988, pg D-5) These results were taken as evidence that the MODFLOW computer code was correctly implemented and operating as expected

4.3 IMPLEMENTATION OF THE CONCEPTUAL HYDROGEOLOGIC MODEL

The conceptual hydrogeologic model is emulated by the computer flow model by designating input parameters appropriate for the site The current version of the RFP site-wide flow model focuses on the waters in the unconsolidated surficial materials It treats the Rocky Flats Alluvium, hillslope colluvium, and valley fill materials as a single, unconfined layer within the MODFLOW model The modeling presented here represents conditions during the spring of 1992

4.3.1 Model Domain

4.3.1.1 Spatial Domain

The model covers an areal extent which includes all of the RFP industrial area and a large portion of the RFP buffer zone (Figure 4-1) The extent of the model grid nodes in State Plane coordinates is from 757300 to 742700 feet northing and from 2076100 to 2094300 feet easting The grid is oriented with the rows aligned along an east-west direction This orientation aligns the model grid so that the grid rows are parallel with the predominant groundwater flow direction Currently, the grid is implemented with a node spacing of 200 feet along rows and columns

4.3.1.2 Time Domain

The simulations included in this status report focus on the spring 1992 time period This period was chosen because it is relatively recent, and because the spring of 1992 was a time of relatively high water levels at the RFP This represents a time of large saturated thicknesses, and conditions of important groundwater flow and transport The conditions modeled here are not intended to represent average conditions at the RFP

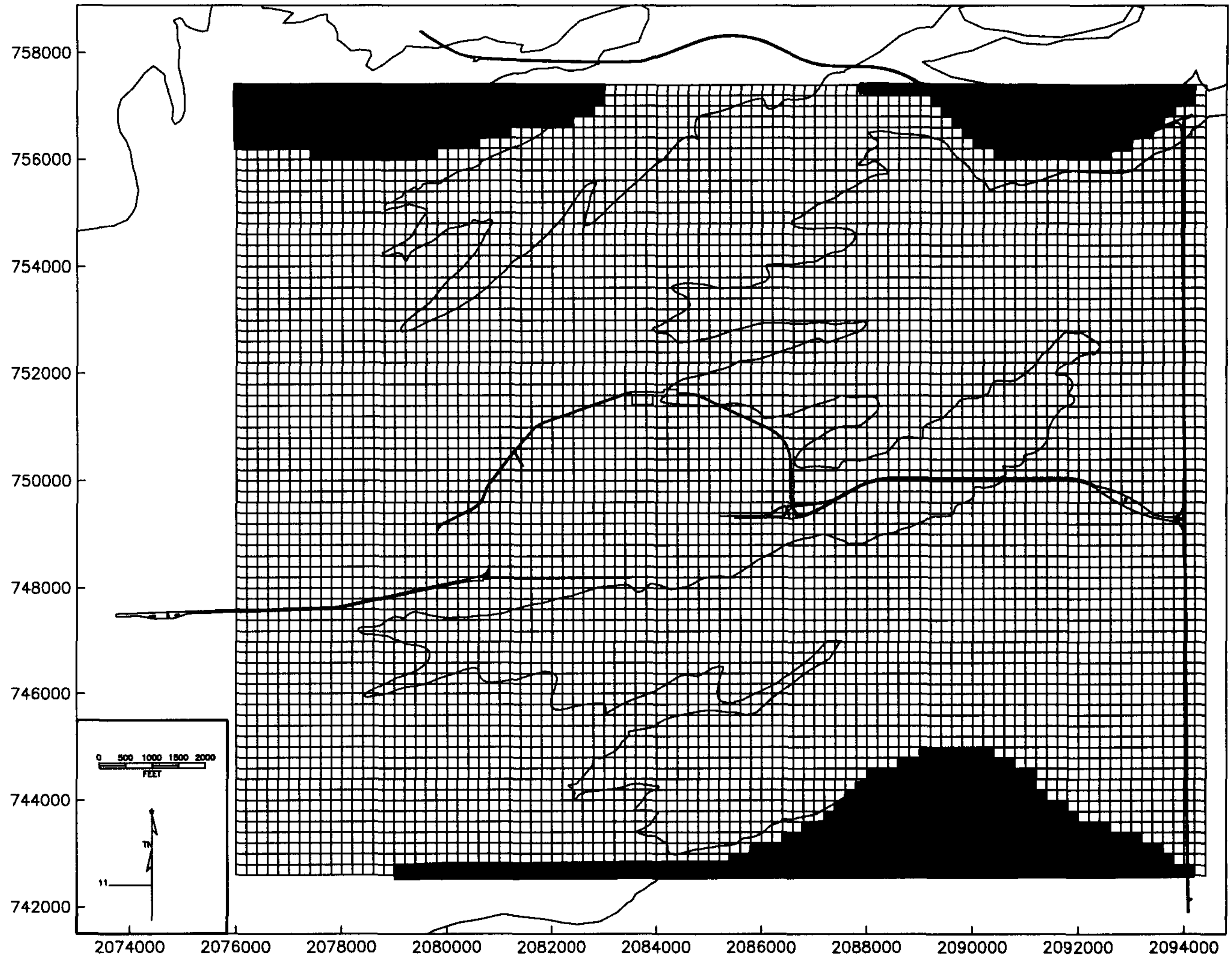

Figure 4-1 The grid network shows the model domain used in the RFP site-wide flow model Grid nodes are at the center of each grid cell Shaded areas represent no-flow boundary conditions All other boundaries are implemented using constant head grid cells The boundary of the Rocky Flats Alluvium and some of the major paved roads at the RFP are provided for reference

To avoid non-convergence and excessive grid node dewatering experienced with attempts at steady-state simulations, the model was run in transient mode The problems encountered with steady-state simulations are likely related to the low hydraulic conductivities, sporadic recharge events, and bedrock topography at the RFP These factors result in a very complex groundwater table that is not well represented by a steady-state simulation To allow the model to equilibrate with the input parameters, the transient simulations were run for long time periods using relatively short time-steps The model was run for 9,132 three-day time-steps (approximately 25 years) This simulation length was thought to be adequate to allow the model to equilibrate to the input data set Maximum water table elevation (head) changes near the end of the simulation were on the order of 0 1 feet over a 24-day time period Average head changes over this period were on the order of 0 004 feet These small head changes over this length of time indicate the model is well equilibrated to the initial input data

4.3.2 Processes Modeled

Some of the factors affecting groundwater flow at the RFP are not incorporated within the subsurface flow system itself These factors are external processes which have a direct influence on the groundwater flow system The two most significant external processes included in the site-wide flow model are areal recharge and loss and gain to surface streams These two factors have an important influence on the head elevations at the RFP and so influence the subsequent flow pattern

4.3 2.1 Recharge From Precipitation

Percolation of meteoric waters through the unsaturated zone to the water table can account for significant recharge to the subsurface flow system There are several factors that influence this process The primary factor that can restrict the amount of infiltrating water available to recharge the groundwater system at the RFP is loss to evapotranspiration The process of evapotranspiration may remove water held in the unsaturated zone before it has an

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opportunity to recharge the saturated zone The potential evapotranspiration at the RFP has been calculated to be approximately 39 inches of water per year (Fedors and Warner, 1993) This value is approximately twice the annual precipitation rate at the RFP This demonstrates the large potential for water loss through evapotranspiration

Although MODFLOW includes a module to model water loss through evapotranspiration, a much simpler and commonly used approach is to look at the net recharge to the groundwater system By using the idea of net recharge, one does not have to be concerned with the actual evapotranspiration values, but only with estimating the amount of water remaining to recharge the groundwater system In MODFLOW this can be done using the recharge package, which adds an areally distributed recharge value (feet/day per unit area) into the flow calculations The values of net recharge used in the site-wide flow model are discussed in section 4 3 3 2

4.3 2.2 Surface Water Recharge And Discharge

The network of surface drainages that cross the RFP can transfer water to and from the groundwater system Initial studies of Woman Creek by Fedors and Warner (1993) indicate that it varies from effluent to influent along its various segments, and that the character of an individual segment may change through time This transfer of water volume between the surface and subsurface flow systems was simulated in the RFP site-wide flow model using the MODFLOW stream-routing package

The stream-routing package compares the head in the stream with the head in the aquifer and computes the direction (to or from the stream) and magnitude (based on the conductance of the stream bed) of water flux The primary drainages at the RFP (Woman, Walnut, and Rock Creek) were initially included in the model Additional drainages were added based on simulation results during the calibration process The only manmade canal currently included in the model is Mower Ditch, which is used to divert water from Woman Creek to Mower Reservoir (section 2 3 4) This was included because a large portion of the flow in Woman

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Creek is continually diverted into this ditch The other irrigation ditches that cross the RFP were not included because they are only used sporadically Specific details regarding input to the stream-routing package are discussed in section 4 3 3 3

Groundwater recharge from ponds within the Woman and Walnut Creek drainages is included in the model using constant head cells All of the A series ponds (with the exception of A-5), B series ponds, C series ponds, and the landfill pond are modeled in this manner The A-5 pond is not currently included because of its small size Pond D-1 is located in a portion of the model with inactive grid nodes, and Pond D-2 is located outside of the area covered by the model

4 3 2.3 Processes Not Currently Modeled

None of the major manmade subsurface water-flow control features discussed in section 2 3 3 has been included in this version of the site-wide flow model This includes the present landfill, solar evaporation ponds, and 881 Hillside subsurface drain systems These features were excluded from the current model as part of a staged approach to avoid unnecessarily complicating the initial version of the model Discussion of including some of these factors in future modeling work is discussed later in this report

4 3.3 Model Parameters

This section reviews the values or range of values of input parameters used for the site-wide flow modeling at the RFP Where available, RFP field measured values were used as a basis for the input values Appropriate literature values were used as guidance when field data were unavailable or had significant uncertainty Some parameters had neither field data nor appropriate literature values In this case professional judgement was used in determining the input value

The input data files for MODFLOW were set up to use length units of feet and time units of days These were the most convenient and applicable units for this project All the data in the following discussion are presented in these units

4.3.3.1 Hydraulic Conductivity

Hydraulic conductivity is a parameter that enters directly into the flux calculations within MODFLOW Field and laboratory measured values of hydraulic conductivity are available for the unconsolidated surficial materials at the RFP Appendix B contains a listing of hydraulic conductivity values determined for materials at the RFP A summary of this information is listed in Table 4 1 As shown by this listing, there is a considerable range in the values of hydraulic conductivity determined for specific material types Some of this variability is associated with differing test conditions and some reflects the heterogeneity of the geologic materials

Table 4 1
Summary of Observed Values of Hydraulic Conductivity (ft/day)

	Minimum	Maximum	Geometric Mean
Rocky Flats Alluvium	8 2E-05	1 4E+02	4 4E-01
Hillslope Colluvium	1 2E-02	6 2E+01	7 2E-01
Valley Fill Alluvium	6 0E-03	1 1E+02	4 0E+00

Table 4 2 provides a summary of the hydraulic conductivity values currently being used in the RFP site-wide flow model A comparison of the values used in the flow model against the observed data (Figure 4-2) verifies that the hydraulic conductivity values used in the model are within the range of the observed data

In determining the initial spatial distribution of hydraulic conductivity values, the model grid was divided into separate regions based on the surficial geologic material These regions were defined as areas covered by Rocky Flats Alluvium, hillslope colluvium, or valley fill alluvium The initial values of hydraulic conductivity for each region were based on the geometric mean of the observed data for that material type This distribution was then adjusted during the model calibration process In the model, hydraulic conductivity is considered isotropic in the north-south and east-west directions

Table 4 2

Summary of Values of Hydraulic Conductivity (ft/day) Used in Model

	Minimum	Maximum	Initial Value
Rocky Flats Alluvium	5 0E-02	1 2E+00	4 4E-01
Hillslope Colluvium	1 0E-01	3 0E+00	7 2E-01
Valley Fill Alluvium	2 0E+00	1 1E+01	1 1E+01/7 6E-01

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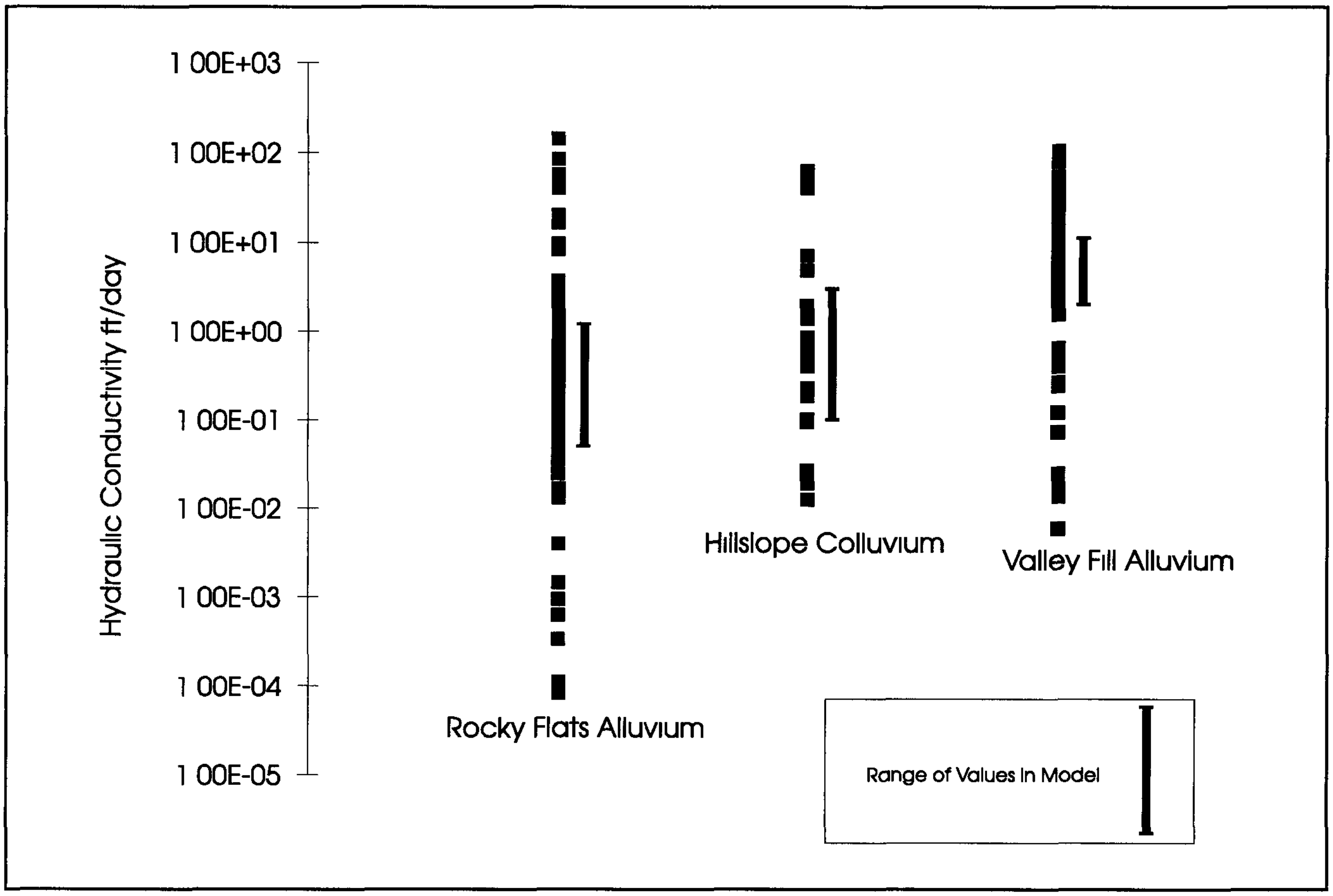

Figure 4-2 Comparison of measured values of hydraulic conductivity, shown by filled squares, and the values used in the flow model, shown by bars

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4.3.3.1 Specific Yield

MODFLOW uses values of specific yield to determine the head change in a cell based on the volumetric water flux into and out of the cell Although estimates of specific yield are available from some of the multi-well pumping tests conducted at the RFP, these values are problematic A multi-well pumping test conducted as part of the OU-1 Phase III investigation produced specific yield values with a mean value of 0 64 (EG&G, 1993) This value is approximately two times the maximum value expected for coarse gravel (Anderson and Woessner, 1992, pg 43, Fetter, 1980, pg 68) Several of the analyses from this study produced specific yield values greater than one, which is not physically possible It is likely that some of the assumptions necessary for the analysis were not valid for the test conditions A series of multi-well pumping tests were also conducted as part of the OU-2 Phase II investigations Although the average value of specific yield (0 04) computed from this testing is plausible for the materials tested (Anderson and Woessner, 1992, pg 43, Fetter, 1980, pg 68), analysis of the test data indicate that the tests were not run long enough to collect data for calculating accurate specific yield values (EG&G, 1992f)

Because of the uncertainty of these values a representative value of 0 10 was adopted for the RFP site-wide flow model This value is consistent with that calculated by Hurr (1976) and lies within the range of values expected for the type of materials under consideration (i e , clay, silt, and sand) (Anderson and Woessner, 1992, pg 43, Fetter, 1980, pg 68) Future work involving re-analysis of previous field tests and the examination of laboratory water-retention curves will help in refining this value This parameter was not adjusted during model calibration

4 3.3.2 Areal Recharge

As dıscussed ın sectıon 4 3 2 1 the RFP sıte-wıde flow model uses a net recharge approach ın ıncorporatıng recharge from precıpıtatıon The process of obtaınıng estımates of recharge ıs problematıc (Anderson and Woessner, 1992) Inıtıal estımates of areal recharge were based on examples from prevıous modelıng projects at the RFP (Fedors and Warner, 1993) The spatıal dıstrıbutıon of these values was based on the general dıstrıbutıon of the dıfferent surfıcıal materıals Thıs was done ın a fashıon sımılar to that used for hydraulıc conductıvıty (sectıon 4 3 2 1) Informatıon from the Soıl Conservatıon Servıce Soıl Survey for the Golden Area (U S D A , 1980) was also used as a guıde for the relatıve ınfıltratıon rates of the dıfferent surfıcıal materıals Values of net recharge used ın the model ranged from 0 to 9 0E-04 ft/day A value of zero was used for the hıghly developed areas of the RFP A typıcal value for areas composed of Rocky Flats Alluvıum was 4 5E-04 ft/day Areas of hıllslope colluvıum would typıcally have a value of 8 5E-05 ft/day, wıth valley-fill areas havıng values rangıng between 2 0E-04 to 5 0E-04 ft/day

4.3.3.3 Stream Data

The ınput requırements to the MODFLOW stream-routıng package, as used here, and how these requırements were met are lısted ın Table 4 3

Table 4 3 Stream-routing Data	
Input Data Required	Value Used in Model
inflow at upstream end of stream	Assumed to be zero
stream stage	Assumed to be 0 5 feet
hydraulic conductance of the streambed	Computed using the hydraulic conductivity, stream length, width, stage, and streambed bottom elevation
elevation of the top of the streambed	Topographic elevation
elevation of the bottom of the streambed	Topographic elevation minus three feet or bedrock elevation if alluvium is less than three feet thick
width of the stream channel*	Assumed to be three feet
slope of the stream channel*	Assumed to be 0 020
Manning's roughness coefficient (n)*	Assumed to be 0 035

*used to compute stream stage

The last three parameters in Table 4 3 are used to compute the approximate stream stage The other parameters are used in the calculation of the volumetric water flux to or from the underlying aquifer

The water inflow from upstream stream segments not explicitly modeled were considered to be zero This is physically correct for many streams Those streams that may have some

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contribution from upstream flow were set at zero until reliable stream flow data are obtained The stream stage listed in Table 4 3 is primarily used to compute the conductance of the streambed (McDonald and Harbaugh, 1988, pg 6-10) and the listed value was chosen as being representative Because the inflows to all stream segments are zero, the initial stream stage actually used in the model is equal to the elevation of the top of the streambed (Prudic, 1988, pg 10) The hydraulic conductivity used to compute the streambed conductance is the same conductivity discussed in section 4 3 2 1 The stream length is the straight-line distance of the stream trace across an individual MODFLOW grid-cell, which was computed using digitized stream maps The value of Manning's roughness coefficient was chosen based on communications with the RFP Surface Water Division and values listed in Prudic (1988) The remaining values in Table 4 3 were used as listed

4.3.3 4 Base of Model (Bedrock) Elevation

Because the current flow model only considers the unconsolidated surficial materials, the base of the model was set at the top of bedrock Top of bedrock elevation information is incorporated into the flow model as a two-dimensional grid of values, one value for each grid node

The grid of bedrock elevations was produced using the Dynamic Graphics Incorporated (DGI) surface-interpolation software The original grid was developed using a 100-foot grid spacing This data was then re-sampled at the 200-foot grid spacing used in the flow model The data used to develop this grid comes from a compilation of 734 data points for bedrock elevation assembled from borehole information by the RFP Geosciences Division

The original data set for bedrock elevation was split into two sets, one set containing points within the Rocky Flats Alluvium, the other set containing all other data points This was done under the assumption that these two groups of data points had different characteristics, and could be gridded more effectively if separated This assumption was developed based on

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information indicating that the Rocky Flats Alluvium is lying on top of a bedrock pediment surface (EG&G, 1991) This relatively smooth surface has subsequently been dissected by the modern drainage systems of Walnut and Woman Creeks Those data points within the Rocky Flats Alluvium represent bedrock elevations on the pediment surface, all other data points would represent areas impacted by subsequent erosion In addition, previous attempts at creating a bedrock-elevation grid using all the data points simultaneously have demonstrated that subdividing the data set would improved results

The two data sets were gridded separately and the two grids combined to form the final grid Extrapolation into areas without borehole control was performed by extrapolating alluvial thickness from the nearest boreholes and then subtracting this thickness from a previously developed ground-surface elevation grid The ground-surface elevation grid was constructed from USGS Digital Elevation Model data and RFP well/borehole survey data Several grid editing iterations involving the bedrock-elevation and alluvial-thickness grids were performed to produce the final grid (Plate 2)

4 3.3 5 Initial Water-Table Elevation

As a starting point for the simulations, an initial groundwater-elevation (head) grid is input to the MODFLOW model For the RFP site-wide simulations this grid was developed to represent conditions during the spring of 1992 (see section 4 3 1 2) A contour map of this grid is presented on Plate 1

The groundwater-elevation grid represents average groundwater elevations in alluvial materials for the period between April 1 and May 30, 1992 The data to create this grid were retrieved from the Rocky Flats Environmental Data System (RFEDS), and include information from 274 wells, 36 of which were considered to be dry A well was considered to be in a saturated area if at least one measurement from this time period indicated a valid water level measurement (i e , not indicated as dry in RFEDS) The data were split into two sets in a manner similar to that described in section 4 3 2 4

As an aid in the development of the initial-head grid, a saturated-thickness grid was also developed The saturated-thickness grid was produced by subtracting the bedrock-elevation grid from the groundwater-elevation grid Further refinements in the saturated-thickness grid were made by manually adjusting the isopach lines and recreating the grid to reflect the new contour configuration Following this the new saturated-thickness grid was added to the bedrock-elevation grid to recreate the groundwater-elevation grid This process was repeated several times to obtain a satisfactory set of groundwater-elevation and saturated-thickness grids

Both the groundwater-elevation and saturated-thickness grids were produced using the DGI surface-interpolation software The original grids were developed using a 100-foot grid spacing The data were then re-sampled at the 200-foot grid spacing used in the flow model

4.3.3.6 Model Boundary Conditions

As part of the mathematical definition of the flow model, the conditions at the outer boundary of the model grid must be specified In MODFLOW these boundary conditions are typically either no-flow or constant head No-flow boundaries are composed of grid cells that are not active in the flow system Because these cells are not incorporated into the flow system, there is no water flux into or out of this type of cell Constant head boundaries are composed of grid cells for which the head does not change during the entire simulation Both of these types of boundaries were used for the RFP site-wide flow modeling

The western and eastern grid margins of the flow model were setup as constant head boundaries (Figure 4-1) This was done primarily because there was no well-defined physical flow boundary near these margins The north and south grid margins were composed of a mixture of no-flow and constant head boundaries No-flow boundaries were used where a groundwater flow divide was believed to exist, elsewhere, constant head cells were employed

The outer boundaries of the model were located at such a distance from the main RFP industrial complex that the influence of boundary conditions should be minimal This is particularly true for the north and south boundaries, which have major drainages between themselves and the main RFP complex The primary area of interest that may be influenced by boundary conditions is OU-11 (West Spray Field), which is located near the western grid margin

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5.0 MODEL CALIBRATION

This chapter describes the current calibration status of the RFP site-wide groundwater flow model This includes a description of the goals of the calibration, factors limiting the calibration, the techniques used during calibration, and the results of the calibration

Model calibration is the process of adjusting the model input parameters to minimize the difference between the model output and some set of observed data In the case of the RFP site-wide flow model, the model calibration parameters are the hydraulic conductivity and recharge values, and the observed data are water level elevations measured in wells during the spring of 1992

5.1 CALIBRATION GOAL

In a general sense, the goal of the calibration process is to reduce the difference between the modeled and observed groundwater elevations More specifically, it is typical to define some criteria by which to judge the calibration Several evaluation criteria were used in assessing the RFP site-wide flow model calibration

5.1.1 Calibration Data Set

Of the 274 wells used to develop the initial-head grid (section 4 3 3 5), 36 were dropped from the calibration because they were dry An additional 31 were eliminated to avoid multiple observation points within a single grid cell Eight of the remaining wells were not used because they fell outside of the model study area The remaining 199 wells were used as observation data in the calibration process

5.1.2 Sources of Error

When comparing modeled and observed data, a certain portion of the error is associated with the observed data themselves The error associated with the observation data is primarily due

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to the discrete nature of the model domain Anderson and Woessner (1992) attribute this error to three sources 1) transient effects, 2) scaling effects, 3) interpolation errors

Transient effects are errors associated with averaging observed heads across some time period For the RFP site-wide model this is introduced by using observed heads that represent an average of the period from April 1, 1992 to May 30, 1992 Many of the wells would be expected to have some water level fluctuation during this time period which would not be represented by the model For those observation wells having more than one water level measurement between April 1, 1992 and May 30, 1992, the average fluctuation was 1 5 feet and the maximum fluctuation was 10 5 feet

Scaling effects are errors introduced by heterogeneities within the subsurface materials that are at a scale smaller than an individual model grid cell For example, small volumes of high or low conductivity materials located at an observation well may have a significant influence on water levels in the well, but could not be explicitly included in the flow model Altering the flow model to fit what may be a non-representative water level caused by a small-scale heterogeneity is inappropriate because the model is meant to represent average conditions within a given grid cell

Because calibration data points rarely fall at the center of a grid cell, there is some interpolation error involved in comparing modeled and observed heads For the RFP site-wide flow modeling, a measure of this error can be expressed by comparing the grid of initial heads for the model to the observed data The values of interpolation error for the observation data set used here, ranged from -8 3 to 14 3 feet The mean and standard deviation were 0 5 and 3 0 feet, respectively The absolute value of interpolation errors for the observation wells ranged from 0 04 to 14 3 feet, the average of the absolute values was 2 0 feet

5 1.3 Calibration Goals

To evaluate when the model is close enough to the observed data to be considered calibrated, a set of calibration goals is defined These calibration goals should be set in accordance with the uncertainty contained in the observation data (section 5 1 2) For the RFP site-wide flow model, the largest source of comparison error related to the observation data is that from the data point interpolation Considering this, the calibration goals were set relative to the interpolation error discussed in section 5 1 2

As a first pass calibration check, a series of calibration levels were set and the number of observation points expected to exceed this level of calibration were determined (Table 5 1)

Table 5 1 Calibration Levels

Level	Basis for Level	Calibration Value Range (ft)	% Expected to Exceed this Calibration Value	Number Expected to Exceed this Value
1	Mean $\pm 1\sigma$	-3 to 3	32	64
2	Mean $\pm 2\sigma$	-6 to 6	5	10

Each row in Table 5 1 represents a calibration level (Anderson and Woessner, 1992, pg 244), against which the calibration observation data points were tested The basis for each level is listed in the second column The calibration value range represents the range of acceptable calibration errors for that level These were computed using a mean of zero and a standard deviation of three feet A mean calibration error of zero was used because this is the

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expected value if the errors do not show a positive or negative bias The third column in this table represents the percentage of calibration points expected to exceed that level, assuming the interpolation errors follow a normal distribution The fourth column in Table 5 1 is the number of calibration points expected to exceed that level using a data set of 199 calibration points

The calibration levels in Table 5 1 provide a general feel for the model calibration errors relative to the overall distribution of the interpolation errors To evaluate individual observation points, the calibration error from each point can be compared to its interpolation error Because the interpolation error is error inherent in the specification of the model domain, the model could be considered calibrated when the model calibration errors are less than or equal to the interpolation errors at each observation point For this report, a calibration point was considered calibrated if the calibration error was within two feet of the interpolation error value For example, a calibration point with an interpolation error of one foot was considered within calibration criteria if the model calibration was less than or equal to three feet Two feet was considered the smallest absolute calibration error to be expected at this scale

The RFP site-wide flow model included the MODFLOW stream-routing package to incorporate groundwater/surface-water interactions This package provides estimates of stream discharge along individual reaches of the stream The comparison of computed and observed stream discharge could be used as an additional calibration criteria Because a comparison of this type requires estimates of flow contributions from surface runoff, only a general comparison of stream discharges was made for this report Future work could incorporate a more in-depth comparison, possibly involving information from surface water modeling being conducted by the RFP Surface Water Division

5.2 CALIBRATION PROCESS

During the calibration process, various model parameters are adjusted so that the model output (values of head) more closely match the observed data This is typically an iterative process that involves running the model, evaluating the output, adjusting the input, and running the model again This was the technique used for this project The model output was evaluated against the observation data and against the general pattern of head and head change (drawdown) values In areas with significant calibration errors, the model inputs were adjusted The hydraulic conductivity and net recharge values were the model inputs changed during model calibration Either one, or both of these parameters were adjusted depending on the magnitude of the calibration error and the hydrogeologic setting of the area Typically during the calibration process, hydraulic conductivity was the first parameter adjusted In areas where the modeled heads were too high, the conductivity values were increased, in areas where the modeled heads were too low, conductivity values were decreased If adjustments of the hydraulic conductivity values within the expected ranges (see Table 4 1) were not adequate to improve the calibration, then the values of areal recharge were adjusted Recharge values were increased to increase the modeled heads, or decreased to decrease the modeled head elevations Because the streambed conductance parameter for the stream-routing package is influenced by the hydraulic conductivity (section 4 3 3 3), these terms were recalculated whenever hydraulic conductivity values were altered

5.3 CURRENT CALIBRATION STATUS

The results presented here reflect the current status of the model calibration and do not necessarily represent conditions of a final calibration Because of the location of the OUs, and the relative density of observation wells, more emphasis was placed on calibrating those areas in and surrounding the RFP industrial area than on the peripheral regions of the RFP

MODFLOW computes a volumetric budget to monitor total mass balance during a simulation to determine whether significant mass balance errors are accumulating The volumetric budget for the site-wide flow model showed a mass balance error (calculated as mass in minus mass out) of -1 26% over the entire simulation Mass balance errors for individual time-steps varied from -0 13% to -2 11% Budget errors for the last portion of the simulation were typically around -0 18% Mass balance errors on the order of 1% are typically considered tolerable (Anderson and Woessner, 1992, pg 223) The mass balance errors for the simulation discussed here are considered to be acceptable

A map showing spring 1992 water elevations contours based on observation well data, and the output from the RFP site-wide flow model was constructed to compare the observed and modeled head configurations (Plate 3) This map illustrates how the flow model tends to smooth out some of the small-scale irregularities in the map of observation data Some of this smoothing is due to the coarseness of the grid used in the flow model The greatest differences between the observed and modeled heads tend to occur at the transition from the gently sloping Rocky Flats Alluvium, to the steeper hillside colluvial materials In addition, areas along the north and south no-flow boundaries, and some of the minor drainages, show some head discrepancies It is impossible to determine the significance of these discrepancies in areas that lack observation wells

Some locations near the RFP industrial area that show notable calibration error are near the present landfill, and in the eastern-half of Operable Unit 2 The discrepancy at the present landfill is due to the exclusion of the landfill subsurface drain system from the present model The discrepancy at Operable Unit 2 indicates additional calibration of hydraulic conductivity and recharge parameters is needed in that region

Table 5 2 presents the actual number of observation points that currently exceed the calibration levels specified in Table 5 1 This table shows that 94 of the 199 calibration points have calibration errors larger than three feet and 49 have errors larger than six feet Conversely, 105 calibration points (53%) have calibration errors of three feet or less, and 150

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(75%) have errors of six feet or less The actual number of calibration points exceeding each calibration level are larger than the expected values, indicating the model calibration can likely be improved

Table 5 2 Calibration Results Compared to Levels			
Level	Calibration Value Range (ft)	Number Expected to Exceed this Value	Number that Actually Exceeded this Value
1	-3 to 3	64	94
2	-6 to 6	10	49

Compared on a point by point basis, 74 (37%) of the calibration points exceeded their associated interpolation error by more than two feet (Figure 5-1) (see section 5 1 3) Conversely, 125 points (63%) were calibrated within two feet of their interpolation error (Figure 5-2)

Information from the RFP Surface Water Division shows the discharge rate from Pond C-1, within the Woman Creek Drainage, as ranging from approximately 500 to 120 gallons per minute (gpm) during April, 1992 The RFP site-wide model indicates discharges of approximately 3 to 4 gpm for stream segments directly upstream from Pond C-1 The large difference between these discharge values can likely be attributed to sources of surface water not accounted for in the flow model These would include, surface runoff from snow-melt, direct precipitation, and irrigation water transfers (this segment of Woman Creek is used as part of a canal system to transfer water from Rocky Flats Lake) Further analysis of this type of calibration may be possible with additional information

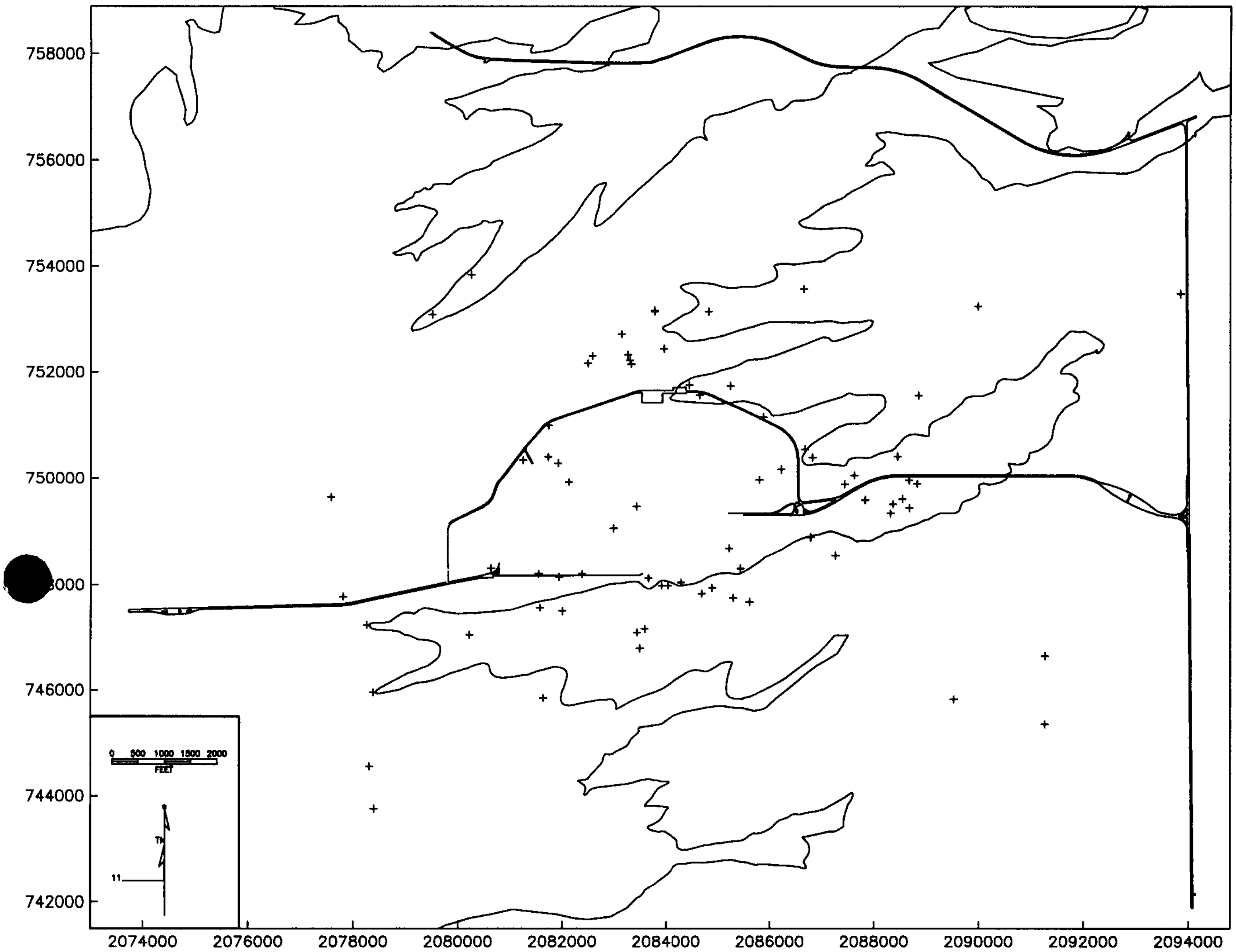

Figure 5-1 The + symbols show the locations of observation points with calibration errors more than two feet greater than their associated interpolation error The outline of the Rocky Flats Alluvium and some of the major paved roads are shown for reference

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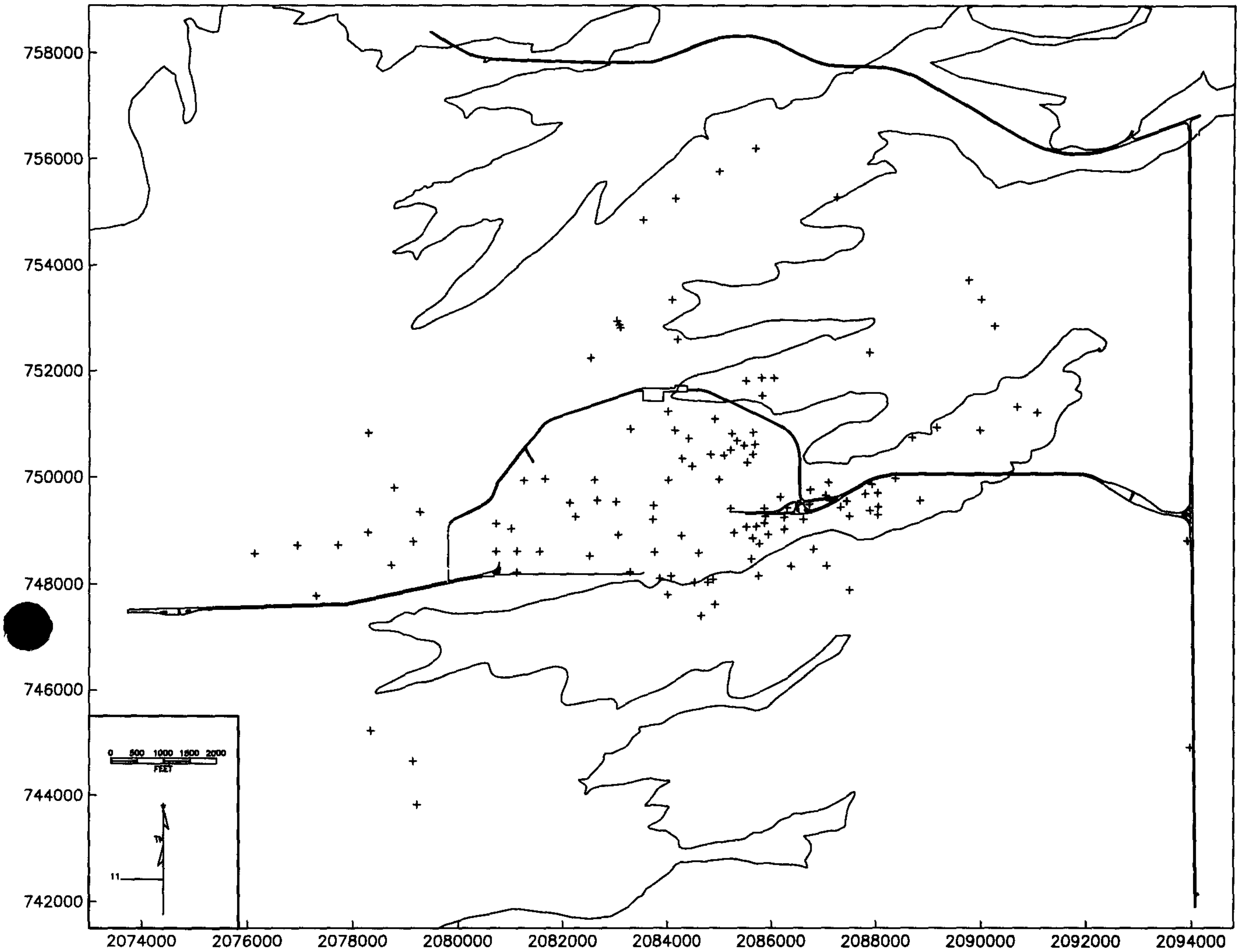

Figure 5-2 The + symbols show the locations of observation points which are calibrated within two feet of their associated interpolation error The outline of the Rocky Flats Alluvium and some of the major paved roads are shown for reference

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The above analysis of the flow model calibration results indicates that additional improvement is possible In particular, significant improvements should be possible at those points that have calibration errors much larger than their associated interpolation errors (figure 5-1) Additional emphasis should also be placed on areas with surface drainage features

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6.0 SUMMARY AND FUTURE WORK

The RFP site-wide flow model is being developed to help in the general characterization of the hydrologic system at the RFP, and to assist investigations for individual OUs The development and current status of the flow model have been discussed in previous chapters of this report Some observations and insights regarding the flow model, along with suggestions for improving the model are given below

6.1 OBSERVATIONS

A primary observation regarding this project, is that the general pattern of modeled heads matches head contours developed from observation data fairly well (Plate 3) In addition, the model is able to produce this relatively realistic head distribution using hydraulic conductivity values within the range of those observed at the RFP (Figure 4-2)

An insight gained from this initial work, is that some decrease in grid node spacing may be necessary if a closer match between observed and modeled heads is required A decrease in the grid node spacing will increase the accuracy of the bedrock and water-table elevation grids used in the model, and reduce the interpolation error for many observation data points This should provide an improvement in the calibration of the flow model Another improvement suggested from this early work, is the need to incorporate the groundwater interception system at the present landfill into the model This will be necessary if the calibration in that area is to be improved (see Plate 3) The modeled heads around the present landfill are above the observed heads, and incorporation of the ground water interception system may increase the accuracy of the model results in this area

6.2 IMPROVEMENTS

The calibration results and discussion presented in this status report suggest several areas of improvement These are presented according to priority, and grouped according to whether they are necessary or suggested improvements

6.2.1 Necessary Improvements

These improvements are considered necessary to improve confidence in the flow model These should be seen as a continuation of the work presented in this status report

As discussed in section 5 3, additional improvements in the model calibration are possible and necessary This will involve a continuation of the calibration process as presented in section 5 2 This process will be concentrated at those areas with a large calibration error relative to their interpolation error, as these locations show the greatest prospect for improvement in the model calibration

Specific yield is a model parameter that is relatively uncertain Analysis regarding values of this parameter using site specific information would provide more confidence for values used in the model This parameter may affect the model calibration to some degree If site specific values are determined that are significantly different that those used in the calibration, additional calibration work may be needed

6.2.2 Suggested Improvements

The following improvements, although not considered absolutely necessary, would significantly increase confidence in the model and the model's applicability Some suggested improvements may become necessary if the scope of uses for the flow model increases

The first, and highest priority improvement, is to restructure the grid node network for the flow model Currently the model uses a node spacing of 200 feet This spacing is adequate for most areas where the surficial materials are relatively flat-lying However, in areas of abrupt slope changes, a finer node spacing would improve the model results A finer node spacing would also improve model response in and around the smaller drainages within the model domain A refinement in the node spacing would become necessary if detailed, concentrated flow modeling were to be attempted for the inner industrial complex at the RFP

Because there are some established anthropogenic effects on the subsurface flow system at the RFP (section 2 3 3), incorporation of these should improve the model's representation of the flow system The subsurface drain system at the present landfill is a prime example of this because its effect on the groundwater system is not reflected by the present model (section 5 3) Incorporation of the french drain system on the 881 Hillside will also be needed if simulations representing periods after installation of the drain are to be done Any detailed flow modeling of the inner industrial complex might require incorporation of some of the major building footer drains Because of their relatively small size, including any of the subsurface drainage systems discussed above would likely involve a refinement in the model node spacing

An additional means of increasing overall confidence in the flow model, would be to incorporate more detailed stream flow data into the calibration process Although this is not a direct improvement to the model, it would provide another independent calibration check This would also provide a cross check between the subsurface flow modeling presented here, and the surface water flow modeling being performed by the RFP Surface Water Division

For some of the work being done at the RFP, the Uppermost Hydrostratigraphic Unit (UHSU) is considered to consist of the unconsolidated surficial materials, any subcropping sandstone bodies, and some portion of the weathered bedrock (EG&G, 1992d) For the site-wide flow model to more closely follow this definition of the UHSU, components of the bedrock flow system would need to be added to the model Assuming the subcropping sandstones have hydraulic conductivities similar to that of the Rocky Flats Alluvium, incorporation of the subcropping sandstone may be possible by increasing the model layer thickness to include the sandstone bodies Including weathered bedrock would likely involve adding an additional layer to the model

Another possible improvement to the model is to investigate the amount of water lost from the near surface flow system to the deeper bedrock system Although some loss to bedrock is likely, it is currently considered to be small Additional analyses could aid in determining whether this assumption is correct Adding this type of discharge to the present flow model can be done using standard packages included with the MODFLOW model

To model the transient, seasonal water level fluctuations observed at the RFP requires that the model be capable of resaturating dry grid nodes The standard MODFLOW model does not include this capability An additional module, BCF2 (McDonald et al , 1991) is available to add this capability This module allows grid cells to desaturate and then resaturate Incorporating this module into the present model would involve some minor recalibration

6.3 SUMMARY

In general, the version of the RFP site-wide flow model presented in this report, is capable of generating water-table elevations which closely match those from observation wells (Plate 3) However, some specific areas for improvement in the model head calibration have been identified (section 5 3), and will need to be addressed in future work Although stream-aquifer interactions have been included in the model, stream-flow data from the model is not currently used as a calibration criteria Comparison of modeled stream-flow and field measured values maybe possible as additional data become available Although the model provides a relatively representative water-table elevation distribution, additional calibration improvements should be performed before the model is used for site-wide or OU specific assessments Additional improvements related to specific yield values and grid node spacing should also be considered

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APPENDIX A

MODFLOW SAMPLE PROBLEM OUTPUT

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Appendix A.1

MODFLOW Sample Problem Output

as Documented in McDonald and Harbaugh, 1988

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                    U S  GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
SAMPLE----3 LAYERS  15 ROWS  15 COLUMNS  STEADY STATE  CONSTANT HEADS COLUMN 1  LAYERS 1 AND 2  RECHARGE  WELLS AND DRAINS

   3 LAYERS         15 ROWS         15 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS SECONDS
I/O UNITS
ELEMENT OF IUNIT   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
        I/O UNIT  11 12 13  0  0  0  0 18 19  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
BAS1 -- BASIC MODEL PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT  1
ARRAYS RHS AND BUFF WILL SHARE MEMORY
START HEAD WILL NOT BE SAVED -- DRAWDOWN CANNOT BE CALCULATED
    5892 ELEMENTS IN X ARRAY ARE USED BY BAS
    5892 ELEMENTS OF X ARRAY USED OUT OF  517000
BCF2 -- BLOCK-CENTERED FLOW PACKAGE  VERSION 2  7/1/91 INPUT READ FROM UNIT 11
STEADY-STATE SIMULATION
HEAD AT CELLS THAT CONVERT TO DRY=    00000E+00
WETTING CAPABILITY IS NOT ACTIVE
     LAYER  AQUIFER TYPE
     -------------------
        1         1
        2         0
        3         0
     453 ELEMENTS IN X ARRAY ARE USED BY BCF
    6345 ELEMENTS OF X ARRAY USED OUT OF  517000
WEL1 -- WELL PACKAGE  VERSION 1  9/1/87 INPUT READ FROM 12
MAXIMUM OF   15 WELLS
      60 ELEMENTS IN X ARRAY ARE USED FOR WELLS
    6405 ELEMENTS OF X ARRAY USED OUT OF  517000
DRN1 -- DRAIN PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT 13
MAXIMUM OF    9 DRAINS
      45 ELEMENTS IN X ARRAY ARE USED FOR DRAINS
    6450 ELEMENTS OF X ARRAY USED OUT OF  517000
RCH1 -- RECHARGE PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT 18
OPTION 1 -- RECHARGE TO TOP LAYER
     225 ELEMENTS OF X ARRAY USED FOR RECHARGE
    6675 ELEMENTS OF X ARRAY USED OUT OF  517000
SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT 19
MAXIMUM OF  50 ITERATIONS ALLOWED FOR CLOSURE
 5 ITERATION PARAMETERS
    2905 ELEMENTS IN X ARRAY ARE USED BY SIP
    9580 ELEMENTS OF X ARRAY USED OUT OF  517000

SAMPLE----3 LAYERS  15 ROWS  15 COLUMNS  STEADY STATE  CONSTANT HEADS COLUMN 1  LAYERS 1 AND 2  RECHARGE  WELLS AND DRAINS

                                       BOUNDARY ARRAY FOR LAYER  1 WILL BE READ ON UNIT  1 USING FORMAT  (15I3)
                              ------------------------------------------------------------------------------------------------

       1   2   3   4   5   6   7   8   9  10  11  12  13  14  15

  1   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  2   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  3   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  4   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  5   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  6   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  7   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  8   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  9   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 10   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 11   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 12   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 13   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 14   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 15   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

                                       BOUNDARY ARRAY FOR LAYER  2 WILL BE READ ON UNIT  1 USING FORMAT  (15I3)
                              ------------------------------------------------------------------------------------------------

       1   2   3   4   5   6   7   8   9  10  11  12  13  14  15

  1   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  2   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  3   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  4   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  5   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  6   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  7   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  8   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
  9   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 10   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 11   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 12   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 13   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 14   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 15   -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
                                                              BOUNDARY ARRAY =            1 FOR LAYER  3

AQUIFER HEAD WILL BE SET TO  999 99     AT ALL NO-FLOW NODES (IBOUND=0)
                                                                INITIAL HEAD =     0000000E+00 FOR LAYER  1
                                                                INITIAL HEAD =     0000000E+00 FOR LAYER  2
                                                                INITIAL HEAD =     0000000E+00 FOR LAYER  3

DEFAULT OUTPUT CONTROL -- THE FOLLOWING OUTPUT COMES AT THE END OF EACH STRESS PERIOD
TOTAL VOLUMETRIC BUDGET
            HEAD
                                                    COLUMN TO ROW ANISOTROPY =    1 000000
                                                                        DELR =    5000 000
                                                                        DELC =    5000 000
                                                       HYD  COND  ALONG ROWS =     1000000E-02 FOR LAYER  1
```


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BOTTOM = -150 0000 FOR LAYER 1
VERT HYD COND /THICKNESS = 2000000E-07 FOR LAYER 1
TRANSMIS ALONG ROWS = 1000000E-01 FOR LAYER 2
VERT HYD COND /THICKNESS = 1000000E-07 FOR LAYER 2
TRANSMIS ALONG ROWS = 2000000E-01 FOR LAYER 3

SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE

MAXIMUM ITERATIONS ALLOWED FOR CLOSURE = 50
ACCELERATION PARAMETER = 1 0000
HEAD CHANGE CRITERION FOR CLOSURE = 10000E-02
SIP HEAD CHANGE PRINTOUT INTERVAL = 1

5 ITERATION PARAMETERS CALCULATED FROM SPECIFIED WSEED = 00100000

0000000E+00 8221720E+00 9683772E+00 9943766E+00 9990000E+00

STRESS PERIOD NO 1 LENGTH = 86400 00

NUMBER OF TIME STEPS = 1

MULTIPLIER FOR DELT = 1 000

INITIAL TIME STEP SIZE = 86400 00

15 WELLS

LAYER	ROW	COL	STRESS RATE	WELL NO
3	5	11	-5 0000	1
2	4	6	-5 0000	2
2	6	12	-5 0000	3
1	9	8	-5 0000	4
1	9	10	-5 0000	5
1	9	12	-5 0000	6
1	9	14	-5 0000	7
1	11	8	-5 0000	8
1	11	10	-5 0000	9
1	11	12	-5 0000	10
1	11	14	-5 0000	11
1	13	8	-5 0000	12
1	13	10	-5 0000	13
1	13	12	-5 0000	14
1	13	14	-5 0000	15

9 DRAINS

LAYER	ROW	COL	ELEVATION	CONDUCTANCE	DRAIN NO
1	8	2	0000E+00	1 000	1
1	8	3	0000E+00	1 000	2
1	8	4	10 00	1 000	3
1	8	5	20 00	1 000	4
1	8	6	30 00	1 000	5
1	8	7	50 00	1 000	6
1	8	8	70 00	1 000	7
1	8	9	90 00	1 000	8
1	8	10	100 0	1 000	9

RECHARGE = 3000000E-07

31 ITERATIONS FOR TIME STEP 1 IN STRESS PERIOD 1
MAXIMUM HEAD CHANGE FOR EACH ITERATION

HEAD CHANGE	LAYER	ROW	COL	HEAD CHANGE	LAYER	ROW	COL	HEAD CHANGE	LAYER	ROW	COL	HEAD CHANGE	LAYER	ROW	COL	HEAD CHANGE	LAYER	ROW	COL
-22 41	(3	5	11)	12 48	(1	1	15)	13 39	(3	1	14)	48 21	(1	1	15)	35 91	(3	1	13)
2 482	(1	9	14)	1 430	(3	10	13)	6 214	(1	12	14)	7 411	(3	11	14)	13 66	(1	15	15)
5503	(3	8	7)	4821	(2	6	9)	4711	(3	5	10)	2 019	(1	11	14)	2 302	(3	5	13)
1108	(1	13	12)	7059E-01	(3	12	11)	2819	(1	14	14)	3141	(3	13	14)	3320	(1	15	15)
7853E-02	(1	13	12)	1586E-01	(2	11	11)	1777E-01	(3	11	10)	7910E-01	(1	14	14)	8499E-01	(3	7	14)
4169E-02	(1	13	14)	2555E-02	(3	14	15)	9769E-02	(1	14	14)	1082E-01	(3	13	14)	1030E-01	(1	15	15)
2430E-03	(1	13	12)																

HEAD IN LAYER 1 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15					
1	0 0000E+00	24 94	44 01	59 26	71 82	82 52	91 91	100 0	106 9	112 6
	117 4	121 3	124 3	126 4	127 4					
2	0 0000E+00	24 45	43 10	57 98	70 17	80 57	90 12	98 40	105 3	111 0
	115 7	119 6	122 7	124 9	126 1					
3	0 0000E+00	23 45	41 30	55 43	66 78	76 21	86 51	95 20	102 2	107 6
	112 0	116 1	119 6	122 1	123 4					
4	0 0000E+00	21 92	38 61	51 75	61 79	68 03	81 34	90 75	97 64	102 5
	106 1	110 7	114 9	117 9	119 4					
5	0 0000E+00	19 73	34 92	47 32	57 69	66 74	77 09	85 76	92 22	96 15
	97 29	103 1	108 8	112 5	114 3					
6	0 0000E+00	16 51	29 50	40 90	51 30	61 21	71 19	79 85	86 47	90 82
	93 03	94 23	102 1	106 4	108 4					
7	0 0000E+00	11 55	21 10	31 21	41 40	51 84	63 08	72 68	79 95	84 92
	88 60	91 66	96 43	99 82	101 8					
8	0 0000E+00	3 483	6 832	16 25	26 30	36 97	52 59	64 31	72 52	77 25
	81 99	85 00	89 27	91 72	94 33					
9	0 0000E+00	10 54	19 11	28 12	36 92	45 27	52 95	55 38	65 15	66 07
	73 93	73 79	80 84	80 17	86 49					
10	0 0000E+00	14 62	25 86	35 38	43 49	50 11	54 93	57 55	62 95	65 55
	70 39	72 44	76 72	78 26	81 79					
11	0 0000E+00	17 11	29 96	40 01	47 78	53 24	55 81	53 33	60 27	59 29

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	66 43	65 45	72 22	71 04	77 62					
12	0 0000E+00	18 68	32 56	43 07	50 81	55 92	58 33	58 47	61 93	63 18
	67 12	68 50	72 29	73 46	76 85					
13	0 0000E+00	19 67	34 24	45 14	53 01	58 04	59 91	56 75	62 59	60 91
	67 22	65 75	71 90	70 35	76 48					
14	0 0000E+00	20 27	35 27	46 48	54 61	60 08	63 17	64 52	67 25	68 79
	71 64	73 18	75 84	77 03	79 09					
15	0 0000E+00	20 56	35 78	47 16	55 48	61 26	65 02	67 52	69 94	72 01
	74 29	76 22	78 22	79 66	80 82					

HEAD IN LAYER 2 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15					
1	0 0000E+00	24 66	43 73	59 02	71 61	82 32	91 72	99 86	106 7	112 5
	117 2	121 1	124 1	126 2	127 3					
2	0 0000E+00	24 17	42 83	57 74	69 95	80 36	89 93	98 22	105 1	110 8
	115 5	119 4	122 6	124 8	125 9					
3	0 0000E+00	23 17	41 03	55 19	66 53	75 77	86 29	95 02	102 0	107 4
	111 8	116 0	119 5	121 9	123 2					
4	0 0000E+00	21 65	38 34	51 50	61 35	60 17	80 90	90 55	97 45	102 3
	105 4	110 4	114 8	117 7	119 2					
5	0 0000E+00	19 48	34 65	47 07	57 44	66 30	76 85	85 57	92 00	95 41
	91 09	102 1	108 6	112 4	114 2					
6	0 0000E+00	16 27	29 24	40 65	51 07	60 98	70 98	79 65	86 28	90 54
	92 06	86 23	101 7	106 2	108 3					
7	0 0000E+00	11 38	20 95	31 05	41 25	51 70	62 90	72 48	79 76	84 73
	88 35	91 24	96 22	99 65	101 6					
8	0 0000E+00	4 209	8 330	17 58	27 58	38 25	52 94	64 19	72 34	77 12
	81 81	84 86	89 10	91 59	94 17					
9	0 0000E+00	10 38	18 96	27 98	36 79	45 16	52 86	56 13	65 08	66 79
	73 87	74 48	80 77	80 84	86 38					
10	0 0000E+00	14 40	25 61	35 15	43 27	49 91	54 76	57 48	62 79	65 49
	70 24	72 37	76 57	78 20	81 64					
11	0 0000E+00	16 87	29 70	39 78	47 56	53 05	55 68	54 09	60 20	60 04
	66 37	66 18	72 16	71 75	77 51					
12	0 0000E+00	18 43	32 31	42 85	50 60	55 73	58 16	58 41	61 78	63 12
	66 98	68 44	72 15	73 40	76 69					
13	0 0000E+00	19 42	33 98	44 91	52 80	57 85	59 78	57 50	62 53	61 65
	67 16	66 48	71 84	71 06	76 37					
14	0 0000E+00	20 02	35 02	46 26	54 41	59 88	62 99	64 39	67 08	68 66
	71 48	73 06	75 68	76 91	78 93					
15	0 0000E+00	20 30	35 52	46 94	55 28	61 07	64 84	67 34	69 76	71 84
	74 11	76 04	78 04	79 49	80 65					

HEAD IN LAYER 3 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15					
1	1 800	24 34	43 36	58 70	71 33	82 06	91 48	99 63	106 5	112 3
	117 0	120 9	123 9	126 0	127 1					
2	1 764	23 85	42 46	57 42	69 66	80 07	89 68	97 99	104 9	110 6
	115 3	119 2	122 4	124 6	125 7					
3	1 691	22 86	40 67	54 87	66 20	75 28	85 98	94 77	101 7	107 2
	111 5	115 7	119 3	121 7	123 0					
4	1 578	21 35	37 98	51 17	60 85	62 69	80 41	90 28	97 19	101 9
	104 1	110 0	114 5	117 5	119 0					
5	1 415	19 18	34 30	46 75	57 10	65 80	76 54	85 30	91 67	94 17
	77 46	100 7	108 2	112 1	114 0					
6	1 176	15 99	28 91	40 33	50 76	60 67	70 70	79 38	86 01	90 12
	90 60	88 55	101 2	106 0	108 0					
7	8273	11 21	20 79	30 88	41 09	51 55	62 67	72 22	79 50	84 46
	87 98	90 77	95 94	99 41	101 4					
8	4331	5 131	10 19	19 27	29 19	39 84	53 40	64 07	72 11	76 95
	81 58	84 68	88 88	91 44	93 95					
9	7543	10 22	18 82	27 84	36 66	45 06	52 78	57 03	65 02	67 64
	73 81	75 31	80 72	81 64	86 24					
10	1 039	14 13	25 29	34 85	42 99	49 65	54 54	57 44	62 61	65 44
	70 05	72 33	76 39	78 15	81 43					
11	1 224	16 59	29 37	39 47	47 28	52 79	55 53	55 01	60 16	60 94
	66 33	67 06	72 13	72 60	77 38					
12	1 341	18 15	31 97	42 54	50 32	55 47	57 94	58 37	61 60	63 08
	66 80	68 41	71 97	73 36	76 49					
13	1 415	19 14	33 65	44 61	52 53	57 60	59 63	58 39	62 48	62 54
	67 12	67 35	71 80	71 90	76 24					
14	1 460	19 73	34 68	45 96	54 13	59 63	62 76	64 24	66 87	68 52
	71 27	72 91	75 47	76 77	78 71					
15	1 481	20 01	35 18	46 63	55 00	60 81	64 59	67 11	69 52	71 61
	73 87	75 82	77 81	79 27	80 42					

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME STEP	L**3/T
IN		IN	
STORAGE =	00000E+00	STORAGE =	00000E+00
CONSTANT HEAD =	00000E+00	CONSTANT HEAD =	00000E+00
WELLS =	00000E+00	WELLS =	00000E+00
DRAINS =	00000E+00	DRAINS =	00000E+00
RECHARGE =	13608E+08	RECHARGE =	157 50
TOTAL IN =	13608E+08	TOTAL IN =	157 50
OUT		OUT	
STORAGE =	00000E+00	STORAGE =	00000E+00

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CONSTANT HEAD =	43265E+07	CONSTANT HEAD =	50 075
WELLS =	64800E+07	WELLS =	75 000
DRAINS =	28011E+07	DRAINS =	32 420
RECHARGE =	00000E+00	RECHARGE =	00000E+00
TOTAL OUT =	13608E+08	TOTAL OUT =	157 50
IN - OUT =	397 00	IN - OUT =	45929E-02
PERCENT DISCREPANCY =	00	PERCENT DISCREPANCY =	00

TIME SUMMARY AT END OF TIME STEP 1 IN STRESS PERIOD 1

	SECONDS	MINUTES	HOURS	DAYS	YEARS
TIME STEP LENGTH	86400 0	1440 00	24 0000	1 00000	273785E-02
STRESS PERIOD TIME	86400 0	1440 00	24 0000	1 00000	273785E-02
TOTAL SIMULATION TIME	86400 0	1440 00	24 0000	1 00000	273785E-02

Appendix A.2

Sample Problem Output for MODFLOW

Stream-Aquifer Interaction Package as Documented in Prudic, 1989

```
                     U S  GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
EXAMPLE SIMULATION OF STREAM ROUTING PACKAGE -- STEADY STATE OCTOBER 21  1987   -- STREAM STAGE IS CALCULATED

   1 LAYERS         6 ROWS         6 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS SECONDS
I/O UNITS
ELEMENT OF IUNIT   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
        I/O UNIT   7  0  0  0  0  0  0  0 13  0  0 14 15  0  0  0  0  0  0  0  0  0  0  0
BAS1 -- BASIC MODEL PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT  1
ARRAYS RHS AND BUFF WILL SHARE MEMORY
START HEAD WILL BE SAVED
     340 ELEMENTS IN X ARRAY ARE USED BY BAS
     340 ELEMENTS OF X ARRAY USED OUT OF  517000
BCF2 -- BLOCK-CENTERED FLOW PACKAGE  VERSION 2  7/1/91 INPUT READ FROM UNIT  7
STEADY-STATE SIMULATION
HEAD AT CELLS THAT CONVERT TO DRY=     00000E+00
WETTING CAPABILITY IS NOT ACTIVE
     LAYER  AQUIFER TYPE
     -------------------
        1        0
       1 ELEMENTS IN X ARRAY ARE USED BY BCF
     341 ELEMENTS OF X ARRAY USED OUT OF  517000
STRM -- STREAM PACKAGE  VERSION 1  10/23/87INPUT READ FROM UNIT 15
MAXIMUM OF    23 STREAM NODES

NUMBER OF STREAM SEGMENTS IS     7

NUMBER OF STREAM TRIBUTARIES IS     3


DIVERSIONS FROM STREAMS HAVE BEEN SPECIFIED
STREAM STAGES WILL BE CALCULATED USING A CONSTANT OF       1 4860
     403 ELEMENTS IN X ARRAY ARE USED FOR STREAMS
     744 ELEMENTS OF X ARRAY USED OUT OF 517000
SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE  VERSION 1  9/1/87 INPUT READ FROM UNIT 13
MAXIMUM OF 150 ITERATIONS ALLOWED FOR CLOSURE
 5 ITERATION PARAMETERS
     749 ELEMENTS IN X ARRAY ARE USED BY SIP
    1493 ELEMENTS OF X ARRAY USED OUT OF  517000

EXAMPLE SIMULATION OF STREAM ROUTING PACKAGE -- STEADY STATE OCTOBER 21  1987   -- STREAM STAGE IS CALCULATED
                                                              BOUNDARY ARRAY =             1 FOR LAYER  1
AQUIFER HEAD WILL BE SET TO  999 00     AT ALL NO-FLOW NODES (IBOUND=0)


                                         INITIAL HEAD FOR LAYER  1 WILL BE READ ON UNIT  1 USING FORMAT   (6F8 0)
                             -----------------------------------------------------------------------------------------------

           1           2           3           4           5           6

  1    480 0       480 0       480 0       480 0       480 0       480 0
  2    480 0       480 0       480 0       480 0       480 0       480 0
  3    480 0       480 0       480 0       480 0       480 0       480 0
  4    480 0       480 0       480 0       480 0       480 0       480 0
  5    480 0       480 0       480 0       480 0       480 0       480 0
  6    480 0       480 0       480 0       480 0       480 0       480 0

HEAD PRINT FORMAT IS FORMAT NUMBER   5    DRAWDOWN PRINT FORMAT IS FORMAT NUMBER   5
HEADS WILL BE SAVED ON UNIT  0    DRAWDOWNS WILL BE SAVED ON UNIT  0
OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
                                                    COLUMN TO ROW ANISOTROPY =   1 000000
                                                                        DELR =   1000 000
                                                                        DELC =   1000 000
                                                        TRANSMIS  ALONG ROWS =    8000000E-01 FOR LAYER  1


                                                        SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
                                                        -------------------------------------------
                                               MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =       150
                                                               ACCELERATION PARAMETER =      1 0000
                                                    HEAD CHANGE CRITERION FOR CLOSURE =       10000E-03
                                                    SIP HEAD CHANGE PRINTOUT INTERVAL =       999
                                                    CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED
                                                   STRESS PERIOD NO    1  LENGTH =   1296000
                                                   ----------------------------------------------

                                                   NUMBER OF TIME STEPS =     3

                                                    MULTIPLIER FOR DELT =     1 500

                                                 INITIAL TIME STEP SIZE =   272842 1
```


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23 STREAM NODES

LAYER	ROW	COL	SEGMENT NUMBER	REACH NUMBER	STREAMFLOW	STREAM STAGE	STREAMBED CONDUCTANCE	STREAMBED BOT ELEVATION	STREAMBED TOP ELEVATION
1	1	3	1	1	4 500	495 0	1 200	490 0	492 0
1	2	3	1	2	0000E+00	490 0	6000	485 0	487 0
1	2	3	2	1	1 500	487 0	2000	483 0	485 0
1	3	3	2	2	0000E+00	486 0	4000	482 0	484 0
1	4	3	2	3	0000E+00	484 0	4000	480 0	482 0
1	5	3	2	4	0000E+00	480 0	2000	476 0	478 0
1	2	3	3	1	-1 000	486 0	4000	481 0	483 0
1	3	4	3	2	0000E+00	482 0	1 200	477 0	479 0
1	4	4	3	3	0000E+00	478 0	1 200	473 0	475 0
1	5	4	3	4	0000E+00	475 0	6000	470 0	472 0
1	4	1	4	1	8000	492 0	4000	489 0	490 0
1	4	2	4	2	0000E+00	488 0	3200	485 0	486 0
1	5	2	4	3	0000E+00	483 0	3200	480 0	481 0
1	5	3	4	4	0000E+00	480 0	2000	477 0	478 0
1	5	3	5	1	-1 000	478 0	2000	475 0	476 0
1	5	4	5	2	0000E+00	474 0	2000	471 0	472 0
1	2	6	6	1	1 200	495 0	8000	491 0	493 0
1	3	6	6	2	0000E+00	490 0	8000	486 0	488 0
1	4	5	6	3	0000E+00	480 0	8000	476 0	478 0
1	5	5	6	4	0000E+00	477 0	6000	473 0	475 0
1	5	4	6	5	0000E+00	474 0	2000	470 0	472 0
1	5	4	7	1	-1 000	472 0	6000	467 0	469 0
1	6	4	7	2	0000E+00	469 0	1 200	464 0	466 0

LAYER	ROW	COL	SEGMENT NUMBER	REACH NUMBER	STREAM WIDTH	STREAM SLOPE	ROUGH COEF
1	1	3	1	1	10 00	7000E-02	3000E-01
1	2	3	1	2	10 00	7000E-02	3000E-01
1	2	3	2	1	5 000	2000E-02	2200E-01
1	3	3	2	2	5 000	2000E-02	2200E-01
1	4	3	2	3	5 000	2000E-02	2200E-01
1	5	3	2	4	5 000	4000E-02	2200E-01
1	2	3	3	1	10 00	5000E-02	3000E-01
1	3	4	3	2	10 00	5000E-02	3000E-01
1	4	4	3	3	10 00	5000E-02	3000E-01
1	5	4	3	4	10 00	5000E-02	3000E-01
1	4	1	4	1	5 000	4000E-02	2200E-01
1	4	2	4	2	5 000	4000E-02	2200E-01
1	5	2	4	3	5 000	4000E-02	2200E-01
1	5	3	4	4	5 000	4000E-02	2200E-01
1	5	3	5	1	5 000	5000E-02	2200E-01
1	5	4	5	2	5 000	5000E-02	2200E-01
1	2	6	6	1	5 000	5000E-02	2200E-01
1	3	6	6	2	5 000	8000E-02	2200E-01
1	4	5	6	3	5 000	7000E-02	2200E-01
1	5	5	6	4	5 000	4000E-02	2200E-01
1	5	4	6	5	5 000	3000E-02	2200E-01
1	5	4	7	1	10 00	4000E-02	3000E-01
1	6	4	7	2	10 00	4000E-02	3000E-01

MAXIMUM NUMBER OF TRIBUTARY STREAMS IS 3

STREAM SEGMENT	TRIBUTARY STREAM SEGMENT NUMBERS		
1	0	0	0
2	0	0	0
3	1	0	0
4	0	0	0
5	2	4	0
6	0	0	0
7	3	5	6

DIVERSION SEGMENT NUMBER	UPSTREAM SEGMENT NUMBER
1	0
2	1
3	0
4	0
5	0
6	0
7	0

AVERAGE SEED = 06853892
MINIMUM SEED = 06853892

5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED

0000000E+00 4883367E+00 7382006E+00 8660468E+00 9314611E+00

23 ITERATIONS FOR TIME STEP 1 IN STRESS PERIOD 1

HEAD/DRAWDOWN PRINTOUT FLAG = 0 TOTAL BUDGET PRINTOUT FLAG = 0 CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME

HEAD PRINTOUT	DRAWDOWN PRINTOUT	HEAD SAVE	DRAWDOWN SAVE
0	0	0	0

1 ITERATIONS FOR TIME STEP 2 IN STRESS PERIOD 1
HEAD/DRAWDOWN PRINTOUT FLAG = 0 TOTAL BUDGET PRINTOUT FLAG = 0 CELL-BY-CELL FLOW TERM FLAG = 0
OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME

HEAD PRINTOUT	DRAWDOWN PRINTOUT	HEAD SAVE	DRAWDOWN SAVE
0	0	0	0

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1 ITERATIONS FOR TIME STEP 3 IN STRESS PERIOD 1
MAXIMUM HEAD CHANGE FOR EACH ITERATION

HEAD CHANGE LAYER ROW COL	HEAD CHANGE LAYER ROW COL	HEAD CHANGE LAYER ROW COL	HEAD CHANGE LAYER ROW COL	HEAD CHANGE LAYER ROW COL
9403E-04 (1 5 5)				

HEAD/DRAWDOWN PRINTOUT FLAG = 1   TOTAL BUDGET PRINTOUT FLAG = 1   CELL-BY-CELL FLOW TERM FLAG = 1
OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME

HEAD PRINTOUT	DRAWDOWN PRINTOUT	HEAD SAVE	DRAWDOWN SAVE
1	0	0	0

LAYER	ROW	COLUMN	STREAM NUMBER	REACH NUMBER	FLOW INTO STREAM REACH	FLOW INTO AQUIFER	FLOW OUT OF STREAM REACH	HEAD IN STREAM
1	1	3	1	1	4 50	931	3 57	492 25
1	2	3	1	2	3 57	841	1 23	487 18
1	2	3	2	1	1 50	- 105	1 60	485 26
1	3	3	2	2	1 60	222	1 38	484 25
1	4	3	2	3	1 38	357	1 03	482 22
1	5	3	2	4	1 03	221	805	478 15
1	2	3	3	1	1 23	-1 05	2 27	483 17
1	3	4	3	2	2 27	- 663	2 94	479 21
1	4	4	3	3	2 94	- 612	3 55	475 24
1	5	4	3	4	3 55	455	3 09	472 24
1	4	1	4	1	800	446	354	490 11
1	4	2	4	2	354	339	157E-01	486 06
1	5	2	4	3	157E-01	157E-01	000E+00	481 01
1	5	3	4	4	000E+00	000E+00	000E+00	478 00
1	5	3	5	1	805	- 182	987	476 14
1	5	4	5	2	987	131	855	472 14
1	2	6	6	1	1 20	1 01	187	493 12
1	3	6	6	2	187	187	000E+00	488 03
1	4	5	6	3	000E+00	- 586E-01	586E-01	478 02
1	5	5	6	4	586E-01	586E-01	000E+00	475 02
1	5	4	6	5	000E+00	000E+00	000E+00	472 00
1	5	4	7	1	3 95	-1 30	5 25	469 32
1	6	4	7	2	5 25	-1 25	6 50	466 37

HEAD IN LAYER 1 AT END OF TIME STEP 3 IN STRESS PERIOD 1

	1	2	3	4	5	6
1	487 639	488 554	491 471	488 439	488 579	490 216
2	486 725	486 551	485 779	485 266	487 082	491 854
3	485 985	485 144	483 696	479 763	482 630	485 602
4	486 087	484 345	481 326	475 750	478 073	479 983
5	482 357	480 593	477 047	471 485	474 662	476 275
6	480 392	478 426	474 294	467 409	472 083	474 179

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 3 IN STRESS PERIOD 1

CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME STEP	L**3/T
IN		IN	
STORAGE =	00000E+00	STORAGE =	00000E+00
CONSTANT HEAD =	00000E+00	CONSTANT HEAD =	00000E+00
STREAM LEAKAGE =	67616E+07	STREAM LEAKAGE =	5 2173
TOTAL IN =	67616E+07	TOTAL IN =	5 2173
OUT		OUT	
STORAGE =	00000E+00	STORAGE =	00000E+00
CONSTANT HEAD =	00000E+00	CONSTANT HEAD =	00000E+00
STREAM LEAKAGE =	67615E+07	STREAM LEAKAGE =	5 2172
TOTAL OUT =	67615E+07	TOTAL OUT =	5 2172
IN - OUT =	95 500	IN - OUT =	85354E-04
PERCENT DISCREPANCY =	00	PERCENT DISCREPANCY =	00

TIME SUMMARY AT END OF TIME STEP 3 IN STRESS PERIOD 1

	SECONDS	MINUTES	HOURS	DAYS	YEARS
TIME STEP LENGTH	613895	10231 6	170 526	7 10526	194531E-01
STRESS PERIOD TIME	129600E+07	21600 0	360 000	15 0000	410678E-01
TOTAL SIMULATION TIME	129600E+07	21600 0	360 000	15 0000	410678E-01

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APPENDIX B

Hydraulic Conductivity Data

Note these data are not completely validated and are presented here for informational purposes only

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Rocky Flats Alluvium						
Well ID	**Interval Tested (ft)**	**Aquifer Conditions**	**Initial Sat. Thick (ft)**	**K cm/sec**	**K ft/day**	**Lithologic Unit**
26-86	3 95-11 00	unconfined	7 05	2 90E-08	8 22E-05	Qrf
26-86	3 95-11 00	unconfined	7 05	3 30E-07	9 36E-04	Qrf
26-86	3 95-11 00	unconfined	7 05	2 10E-05	5 95E-02	Qrf
26-86	3 95-11 00	unconfined	7 05	5 10E-07	1 45E-03	Qrf
28-86	6 19-9 96	unconfined	3 77	1 40E-06	3 97E-03	Qrf
10-86	11 05-23 78	unconfined	12 73	8 70E-06	2 47E-02	Qrf
22-86	7 27-11 2	unconfined	3 93	4 00E-08	1 13E-04	Qrf
22-86	7 27-11 2	unconfined	3 93	4 80E-05	1 36E-01	Qrf
22-86	7 27-11 2	unconfined	3 93	1 20E-04	3 40E-01	Qrf
22-86	7 27-11 2	unconfined	3 93	3 10E-05	8 79E-02	Qrf
39-86	23 85-31 50	unconfined	7 65	3 70E-04	1 05E+00	Qrf
42-86	19 96-29 70	unconfined	9 74	5 00E-02	1 42E+02	Qrf
42-86	19 96-29 70	unconfined	9 74	1 29E-04	3 66E-01	Qrf
45-86	22 01-48 20	unconfined	26 19	2 10E-05	5 95E-02	Qrf
45-86	22 01-48 20	unconfined	26 19	8 20E-05	2 32E-01	Qrf
45-86	22 01-48 20	unconfined	26 19	5 60E-05	1 59E-01	Qrf
45-86	22 01-48 20	unconfined	26 19	1 80E-05	5 10E-02	Qrf
47-86	56 80-94 49	unconfined	37 69	2 60E-05	7 37E-02	Qrf
49-86	23 64-67 60	unconfined	23 64	9 67E-05	2 74E-01	Qrf
50-86	46 72-96 15	unconfined	49 43	5 30E-04	1 50E+00	Qrf
56-86	6 16-9 6	unconfined	3 44	5 90E-06	1 67E-02	Qrf
56-86	6 16-9 6	unconfined	3 44	3 90E-04	1 11E+00	Qrf
56-86	6 16-9 6	unconfined	3 44	3 20E-04	9 07E-01	Qrf
56-86	6 16-9 6	unconfined	3 44	3 20E-04	9 07E-01	Qrf
56-86	6 16-9 6	unconfined	3 44	5 00E-05	1 42E-01	Qrf
56-86	6 16-9 6	unconfined	3 44	3 80E-04	1 08E+00	Qrf
56-86	6 16-9 6	unconfined	3 44	1 50E-04	4 25E-01	Qrf
56-86	6 16-9 6	unconfined	3 44	1 00E-04	2 84E-01	Qrf
17-87	18 35-25 50	unconfined	7 15	6 00E-05	1 70E-01	Qrf
17-87	18 35-25 50	unconfined	13 7	5 89E-06	1 67E-02	Qrf
32-87	38 85-46 58	unconfined	7 73	1 20E-03	3 40E+00	Qrf
32-87	38 85-46 58	unconfined	12 88	4 90E-05	1 39E-01	Qrf
58-87	13 80-22 26	unconfined	8 46	1 56E-05	4 42E-02	Qrf
58-87	13 80-22 26	unconfined	38 8	5 50E-06	1 56E-02	Qrf
60-87	11 32-27 47	unconfined	16 15	1 29E-03	3 66E+00	Qrf
60-87	11 32-27 47	unconfined	11 55	5 41E-04	1 53E+00	Qrf

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61-87	12 46-28 24	unconfined	15 78	9 87E-04	2 80E+00	Qrf
61-87	12 46-28 24	unconfined	15 78	9 87E-04	2 80E+00	Qrf
61-87	12 46-28 24	unconfined	38 8	1 35E-04	3 83E-01	Qrf
62-87	12 66-26 56	unconfined	13 9	6 21E-04	1 76E+00	Qrf
62-87	12 66-26 56	unconfined	13 9	6 21E-04	1 76E+00	Qrf
62-87	12 66-26 56	unconfined	38 8	7 67E-05	2 17E-01	Qrf
63-87	14 56-25 40	unconfined	10 84	6 68E-04	1 89E+00	Qrf
63-87	14 56-25 40	unconfined	10 84	6 68E-04	1 89E+00	Qrf
63-87	14 56-25 40	unconfined	38 8	7 00E-05	1 98E-01	Qrf
65-87	12 82-23 96	unconfined	11 14	4 63E-04	1 31E+00	Qrf
65-87	12 82-23 96	unconfined	11 14	4 63E-04	1 31E+00	Qrf
65-87	12 82-23 96	unconfined	38 8	4 98E-05	1 41E-01	Qrf
66-87	11 37-17 96	unconfined	6 59	1 79E-04	5 07E-01	Qrf
66-87	11 37-17 96	unconfined	38 8	1 24E-05	3 52E-02	Qrf
67-87	8 74-16 46	unconfined	5 08	6 42E-05	1 82E-01	Qrf
67-87	8 74-16 46	unconfined	38 8	1 65E-05	4 68E-02	Qrf
71-87	5 67-13 50	unconfined	7 83	6 60E-04	1 87E+00	Qrf
71-87	5 67-13 50	unconfined	11 55	1 63E-04	4 62E-01	Qrf
B400189	22 55-51 64	unconfined	29 09	5 80E-05	1 64E-01	Qrf
B400189	22 55-51 64	unconfined	29 09	7 00E-05	1 98E-01	Qrf
B400189		unconfined	27 53	1 56E-04	4 42E-01	Qrf
B400189		unconfined	27 53	2 00E-04	5 67E-01	Qrf
B400089		unconfined	14 83	5 00E-05	1 42E-01	Qrf
B400289	22 32-51 8	unconfined	35 28	7 60E-04	2 15E+00	Qrf
B400289	22 32-51 8	unconfined	35 28	7 60E-04	2 15E+00	Qrf
B400389	21 42-51 00	unconfined	29 08	1 30E-04	3 69E-01	Qrf
B400389	21 42-51 00	unconfined	29 08	1 80E-04	5 10E-01	Qrf
B400489	12 02-56 60	unconfined	45 73	5 80E-03	1 64E+01	Qrf
B400489	12 02-56 60	unconfined	45 73	7 00E-03	1 98E+01	Qrf
B400489		unconfined	31 66	2 00E-02	5 67E+01	Qrf
B400489		unconfined	31 66	3 00E-02	8 51E+01	Qrf
B200589	21 26-33 34	unconfined	10 51	2 90E-03	8 22E+00	Qrf
B200589	21 26-33 34	unconfined	10 51	1 20E-03	3 40E+00	Qrf
B200689	23 33-32 89	unconfined	9 11	4 30E-04	1 22E+00	Qrf
B200689	23 33-32 89	unconfined	9 11	3 70E-04	1 05E+00	Qrf
B200689	23 33-32 89	unconfined	9 11	3 70E-04	1 05E+00	Qrf
B200689	23 33-32 89	unconfined	9 11	3 70E-04	1 05E+00	Qrf
B200789	21 0-30 48	unconfined	8 98	8 20E-04	2 32E+00	Qrf
B200789	21 0-30 48	unconfined	8 98	8 50E-04	2 41E+00	Qrf
B200889	20 84-25 10	unconfined	3 94	5 20E-04	1 47E+00	Qrf
B200889	20 84-25 10	unconfined	3 94	4 00E-04	1 13E+00	Qrf
B200889	20 84-25 10	unconfined	3 94	5 20E-04	1 47E+00	Qrf
B200889	20 84-25 10	unconfined	3 94	4 90E-04	1 39E+00	Qrf

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B405689	6 95-24 55	unconfined	17 6	2 20E-07	6 24E-04	Qrf
B405689	6 95-24 55	unconfined	17 6	1 20E-07	3 40E-04	Qrf
B405789	44 91-54 38	unconfined	43 88	3 00E-02	8 51E+01	Qrf
B405789	44 91-54 38	unconfined	43 88	1 40E-02	3 97E+01	Qrf
B405789	44 91-54 38	unconfined	41 9	2 00E-02	5 67E+01	Qrf
B405789	44 91-54 38	unconfined	41 9	3 00E-02	8 51E+01	Qrf
B410589	52 47-62 04	unconfined	9 57	2 90E-04	8 22E-01	Qrf
B410589	52 47-62 04	unconfined	9 57	2 30E-04	6 52E-01	Qrf
B410689	41 9-52 06	unconfined	10 16	9 10E-04	2 58E+00	Qrf
B410689	41 9-52 06	unconfined	10 16	7 60E-04	2 15E+00	Qrf
B410789	36 19-46 79	unconfined	10 6	9 80E-04	2 78E+00	Qrf
B410789	36 19-46 79	unconfined	10 6	5 50E-04	1 56E+00	Qrf
B110889	47 47-66 95	unconfined	31 55	3 40E-03	9 64E+00	Qrf
B110889	47 47-66 95	unconfined	31 55	3 30E-03	9 36E+00	Qrf
B110989	48 19-67 67	unconfined	20 05	6 40E-04	1 81E+00	Qrf
B110989	48 19-67 67	unconfined	20 05	7 60E-04	2 15E+00	Qrf
B111189	56 97-74 4	unconfined	17 43	3 00E-04	8 51E-01	Qrf
B111189	56 97-74 4	unconfined	17 43	1 00E-04	2 84E-01	Qrf
B411289	59 74-70 29	unconfined	10 55	1 60E-05	4 54E-02	Qrf
B411289	59 74-70 29	unconfined	10 55	1 30E-05	3 69E-02	Qrf
B411389	53 00-65 08	unconfined	12 08	8 30E-05	2 35E-01	Qrf
B411389	53 00-65 08	unconfined	12 08	7 00E-05	1 98E-01	Qrf
45-86				2 10E-05	5 95E-02	Qrf
45-86				3 90E-05	1 11E-01	Qrf
45-86				2 80E-05	7 94E-02	Qrf
45-86				4 60E-06	1 30E-02	Qrf
15-87				1 00E-03	2 84E+00	Qrf
1-66			22	6 70E-05	1 90E-01	Qrf/Ka?
9-81			27 6	2 90E-05	8 22E-02	Qrf?
10-81			13	2 90E-03	8 22E+00	Qrf?
			Geometric Mean	1 56E-04	4 44E-01	
			Arithmetic Mean	2 28E-03	6 46E+00	
			Maximum	5 00E-02	1 42E+02	
			Minimum	2 90E-08	8 22E-05	
			Logged Standard Deviation	1 47E+01	2 07E+01	

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Hillslope Colluvium						
Well ID	Interval Tested (ft)	Aquifer Conditions	Initial Sat. Thick (ft)	K cm/sec	K ft/day	Lithologic Unit
59-86R		unconfined	3 53	1 50E-02	4 25E+01	Qc
59-86R				1 40E-02	3 97E+01	Qc
69-86	5 70-14 00	unconfined	8 3	1 40E-04	3 97E-01	Qc
69-86	5 70-14 00	unconfined	2 3	6 80E-04	1 93E+00	Qc
69-86	5 70-14 00	unconfined	8 3	2 40E-04	6 80E-01	Qc
69-86	6 68-14 00	unconfined	7 32	1 74E-04	4 93E-01	Qc
69-86	6 68-14 00	unconfined	7 32	4 38E-06	1 24E-02	Qc
4-87	7 99-19 47	unconfined	11 48	6 60E-05	1 87E-01	Qc
4-87	7 99-19 47	unconfined	11 48	8 00E-05	2 27E-01	Qc
B201189	22 27-36 71	unconfined	28 52	9 10E-06	2 58E-02	Qc
B201189	22 27-36 71	unconfined	28 52	9 40E-06	2 66E-02	Qc
B201189	22 27-36 71	unconfined	26 44	4 90E-04	1 39E+00	Qc
B201189	22 27-36 71	unconfined	26 44?	2 00E-04	5 67E-01	Qc
B401989	8 68-23 13	unconfined	17 97	2 90E-04	8 22E-01	Qc
B401989	8 68-23 13	unconfined	17 97	3 00E-04	8 51E-01	Qc
B205589	13 98-18 36	unconfined	4 38	1 70E-03	4 82E+00	Qc
B205589	13 98-18 36	unconfined	4 38	2 50E-03	7 09E+00	Qc
2-87	3 41-11 08	unconfined	7 67	3 40E-05	9 64E-02	Qc
2-87	3 41-11 08	unconfined	7 67	3 60E-05	1 02E-01	Qc
2-87	3 41-11 08	unconfined	6 25	3 60E-05	1 02E-01	Qc
2-87	3 41-11 08	unconfined	7 67	3 30E-05	9 36E-02	Qc
B202589	6 38-13 45	unconfined	8 97	2 20E-02	6 24E+01	Qc
B202589	6 38-13 45	unconfined	8 97	2 00E-02	5 67E+01	Qc
B202589	6 38-13 45	unconfined	8 97	1 90E-02	5 39E+01	Qc
4-87				6 60E-05	1 87E-01	Qc
4-87			6 25	6 70E-06	1 90E-02	Qc
			Geometric Mean	2 54E-04	7 19E-01	
			Arithmetic Mean	3 73E-03	1 06E+01	
			Maximum	2 20E-02	6 24E+01	
			Minimum	4 38E-06	1 24E-02	
			Logged Standard Deviation	7 25E-03	2 06E+01	

Woman Creek Drainage Valley Fill						
Well ID	**Interval Tested (ft)**	**Aquifer Conditions**	**Initial Sat. Thick (ft)**	**K cm/sec**	**K ft/day**	**Lithologic Unit**
O-1		unconfined	3 72	1 90E-02	5 39E+01	Qvf
O-1		unconfined	3 72	2 80E-02	7 94E+01	Qvf
O-1		unconfined	3 72	2 80E-02	7 94E+01	Qvf
O-1		unconfined	3 72	7 80E-03	2 21E+01	Qvf
O-2		unconfined	3 65	1 80E-02	5 10E+01	Qvf
O-2		unconfined	3 65	3 00E-02	8 51E+01	Qvf
O-2		unconfined	3 65	3 10E-02	8 79E+01	Qvf
O-2		unconfined	3 65	1 60E-02	4 54E+01	Qvf
O-3		unconfined	3 37	1 70E-02	4 82E+01	Qvf
O-3		unconfined	3 37	3 00E-02	8 51E+01	Qvf
O-3		unconfined	3 37	5 90E-03	1 67E+01	Qvf
O-3		unconfined	3 37	5 90E-03	1 67E+01	Qvf
I-1		unconfined	3 68	1 90E-02	5 39E+01	Qvf
I-1		unconfined	3 68	3 70E-02	1 05E+02	Qvf
I-1		unconfined	3 68	3 70E-02	1 05E+02	Qvf
I-1		unconfined	3 68	1 40E-02	3 97E+01	Qvf
I-2		unconfined	3 47	1 60E-02	4 54E+01	Qvf
I-2		unconfined	3 47	1 10E-02	3 12E+01	Qvf
65-86	5 30-8 00	unconfined	2 7	2 10E-03	5 95E+00	Qvf
65-86	5 30-8 00	unconfined	1 7	3 50E-03	9 92E+00	Qvf
65-86	5 30-8 00	unconfined	2 7	2 10E-03	5 95E+00	Qvf
68-86	0 92-3 50	unconfined	2 58	5 50E-04	1 56E+00	Qvf
68-86	0 92-3 50	unconfined	1 88	4 40E-03	1 25E+01	Qvf
68-86	0 92-3 50	unconfined	2 58	9 80E-04	2 78E+00	Qvf
70-86	1 74-7 90	unconfined	6 16	1 50E-04	4 25E-01	Qvf
70-86	1 74-7 90	unconfined	4	6 80E-04	1 93E+00	Qvf
70-86	1 74-7 90	unconfined	6 16	2 10E-04	5 95E-01	Qvf
35-86	6 94-11 60	unconfined	4 66	2 60E-05	7 37E-02	Qvf
35-86	7 04-11 60	unconfined	4 59	1 40E-04	3 97E-01	Qvf
35-86	7 04-11 60	unconfined	100	8 77E-06	2 49E-02	Qvf
			Geometric Mean	3 97E-03	1 12E+01	
			Arithmetic Mean	1 28E-02	3 64E+01	
			Maximum	3 70E-02	1 05E+02	
			Minimum	8 77E-06	2 49E-02	
			Logged Standard Deviation	1 24E-02	3 51E+01	

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Walnut Creek Drainage Valley Fill						
Well ID	**Interval Tested (ft)**	**Aquifer Conditions**	**Initial Sat. Thick (ft)**	**K cm/sec**	**K ft/day**	**Lithologic Unit**
1-81		unconfined	10	8 60E-05	2 44E-01	Qvf?
12-86	4 08-11 3	unconfined	7 22	2 00E-04	5 67E-01	Qvf
15-86	4 33-14 69	unconfined	10 36	4 30E-05	1 22E-01	Qvf
17-86	4 63-13 98	unconfined	9 35	4 80E-06	1 36E-02	Qvf
17-86	4 63-13 98	unconfined	9 35	6 50E-06	1 84E-02	Qvf
17-86	4 63-13 98	unconfined	9 35	7 00E-06	1 98E-02	Qvf
17-86	4 63-13 98	unconfined	9 35	2 10E-06	5 95E-03	Qvf
B102289	4 76-14 23	unconfined	11 23	2 30E-04	6 52E-01	Qvf
B102289	4 76-14 23	unconfined	11 23	2 20E-04	6 24E-01	Qvf
B102389	5 74-12 58	unconfined	6 34	1 40E-04	3 97E-01	Qvf
B102389	5 74-12 58	unconfined	6 34	9 40E-05	2 66E-01	Qvf
B202489	9 09-14 83	unconfined	5 24	7 60E-03	2 15E+01	Qvf
B202489	9 09-14 83	unconfined	5 24	1 00E-02	2 84E+01	Qvf
B202489	9 09-14 83	unconfined	5 24	7 30E-03	2 07E+01	Qvf
B202489	9 09-14 83	unconfined	5 24	9 70E-03	2 75E+01	Qvf
B302889	8 25-12 85	unconfined	6 57	2 80E-03	7 94E+00	Qvf
B302889	8 25-12 85	unconfined	6 57	2 20E-03	6 24E+00	Qvf
B302989	5 39-9 83	unconfined	5 52	1 20E-03	3 40E+00	Qvf
B302989	5 39-9 83	unconfined	5 52	1 50E-03	4 25E+00	Qvf
			Geometric Mean	2 68E-04	7 59E-01	
			Arithmetic Mean	2 28E-03	6 47E+00	
			Maximum	1 00E-02	2 84E+01	
			Minimum	2 10E-06	5 95E-03	
			Logged Standard Deviation	3 52E-03	9 98E+00	

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